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Human Error Analysis of Helicopter Emergency Medical Services (HEMS) Accidents Using the Human Factors Analysis and Classification System (HFACS)

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Introduction

On August 26, 2011 a Eurocopter (Airbus Industries) AS350 B2 aircraft crashed after suffering "a loss of engine power as a result of fuel exhaustion" (National Transportation Safety Board [NTSB], 2013). The pilot, flight nurse, flight paramedic and patient were all killed. Day Visual Meteorological Conditions (VMC) prevailed at the time of the accident. The purpose of this flight was an interfacility transfer.

According to the NTSB Final Report (2013), after arriving at the sending facility, the flight nurse and flight paramedic went into the Emergency Department to prepare the patient for transport. The pilot notified the company communications center by cell phone that the helicopter did not have as much fuel on board as previously thought, and they would have to stop en route to the receiving hospital to refuel. Several options were discussed, and the pilot decided they would attempt to make it to an airport 58 nautical miles away. The communications center asked the pilot if he was going to refuel the aircraft and return for the patient, or if they were going to refuel with the patient on board? The pilot stated they would refuel with the patient on board en route to the receiving hospital.

After the patient was loaded, the aircraft took off with 45 minutes of fuel on board. When the pilot failed to report landing at the destination airport, a ground search was initiated. The wreckage was discovered approximately one nautical mile from the approach end of the runway at the destination airport. The Final Report found the probable cause of the crash to be:

> [T]he pilot's failure to confirm that the helicopter had adequate fuel on board to complete the mission before making the first departure, his improper decision to continue the mission and make a second departure after he became aware of a critically low fuel level, and his failure to successfully enter an autorotation when

> the engine lost power due to fuel exhaustion. Contributing to the accident were (1) the pilot's distracted attention due to personal texting during safety-critical ground and flight operations, (2) his degraded performance due to fatigue, (3) the operator's lack of a policy requiring that an operational control center specialist be notified of abnormal fuel situations, and (4) the lack of practice representative of an actual engine failure at cruise airspeed in the pilot's autorotation training in the accident make and model helicopter (NTSB, 2013).

Because of its unique flight environment, helicopter emergency medical services (HEMS) is among the most dangerous types of flying in commercial aviation today (Federal Aviation Administration [FAA], 2014). "The pressure to safely and quickly conduct … operations in various environmental conditions … makes EMS operations inherently dangerous" (NTSB, 2006b, p. vii). Off airport operations, low altitude flight environment, remote and/or challenging locations, spotty or inaccurate weather data along the route of flight, and little or no warning before mission dispatch are all factors which add to the complexity of HEMS flying (Zuccaro, 2009).

This study was conducted to enhance understanding of the factors that contribute to HEMS accidents. Building on prior research, Human Factors Analysis and Classification System (HFACS) was used to examine HEMS accidents for the years 2000-2016. Questions addressed include:

1. Which errors or preconditions occurred most often?
2. Which errors or preconditions were most frequently associated with fatal accidents?
3. During which phase of flight did most of errors take place?
4. How do these findings compare with previous research?

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HFACS

Building on James Reason's (1990) "Swiss Cheese" model of human error, the HFACS system provides investigators with a "comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents" (Shappell & Wiegmann, 2000, p. 13). Originally developed for the Navy and Marine Corps, HFACS is now used by all branches of the military when investigating human error accidents (Bilbro, 2013). It has also been used to examine civilian commercial airline accidents and incidents (Wiegmann & Shappell, 2001).

HFACS divides human failure into four main categories: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. Unsafe acts can be loosely subdivided into two groups: errors and violations. Errors are any action that fails to achieve its intended outcome (Shappell & Wiegmann, 2000). Violations on the other hand, arise because of the "conscious failure to adhere to procedures or regulations" (Helmreich, 2000, p. 782). The main difference between errors and violations is intent: violations are deliberate whereas errors are not.

Within HFACS, errors are further divided according to cause. Skill-based errors represent well practiced behaviors that occur without significant thought. In aviation, these are referred to as the "stick and rudder" skills necessary to safely and competently fly an aircraft (Shappell & Wiegmann, 2000). Skill-based errors occur during routine activities when attention is diverted from a task or there is a failure of memory. In most cases the individual has the knowledge, skills, and experience to perform the action, but something causes the operator's attention to stray or a checklist item is forgotten (von Thaden, Gibbons, & Suzuki, 2007).

Table 1

Unsafe Acts

Errors	Examples
Skill-Based	Breakdown in visual scan Failed to prioritize attention Inadvertent use of flight controls Omitted step in a procedure Omitted checklist item Poor technique Over-controlled the aircraft
Decision Based	Improper procedure Misdiagnosed emergency Wrong response to emergency Exceeded ability Inappropriate maneuver Poor decision
Perceptual Errors (due to)	Misjudged distance/altitude/airspeed Spatial disorientation Visual illusion

Adapted from (Shappell & Wiegmann, 2000, p. 4)

Decision errors "represents intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation" (Shappell & Wiegmann, 2000, p. 4). Decisional errors result from the pilot's failure to choose the correct procedure, adequately diagnose the problem, or make the appropriate choice among competing priorities.

The third major type of error deals with perception. Perceptual errors typically occur when "sensory input is degraded or 'unusual,' as is the case with visual illusions and spatial disorientation, or when aircrews misjudge the aircraft's altitude, attitude, or airspeed" (Shappell & Wiegmann, 2000, p. 5). It is important to stress it is not the illusion or disorientation that is classified as a perceptual error; rather, it is the pilot's inappropriate response to the disturbance.

For example, instrument rated pilots routinely experience visual or vestibular disturbances while flying in Instrument Meteorological Conditions (IMC). Because of this, their training emphasizes relying on the instruments while ignoring their senses. These altered sensations only contribute to error when the pilot fails to adhere to training and responds inappropriately, as is the case when the pilot flies the aircraft under control into the water or ground during a "black hole" approach on a dark, starless night.

The second major cause of unsafe acts are violations. Violations are decisional errors. They are the conscious failure to follow established procedure or rules. Violations may be classified as either routine or exceptional (Shappell & Wiegmann, 2000). Routine violations are usually known by the management structure and tolerated. They traditionally do not have a consequence attached and therefore become part of the company's culture. "Observation shows that if the quickest and most convenient path between two related points involves transgressing an apparently trivial and rarely sanctioned safety procedure, then it will be violated routinely by the operators of the system" (Reason, 1990, sec. 7.2).

Exceptional violations are those that are not tolerated by management and often have significant consequences attached to their discovery. They occur "when an individual is attempting to solve problems in unusual situations. The individual, in attempting to solve new problems, violates a rule to achieve the desired goal. These violations are commonly associated with high risk, often because the consequences of the action are not fully understood or because the violation is known to be dangerous but seems inescapable" (Health and Safety Executive, 1995, p. 9).

In addition to the unsafe acts of the operator, HFACS remains cognizant of how physical and mental limitations, as well as the occupational environment, affect human error. HFACS addresses preconditions, which allow or encourage human error to occur. In terms of the operator (pilot and/or flight crew), HFACS divides preconditions into two classes: substandard condition of the operator and substandard practices of the operator. Substandard condition of the operator include adverse mental states (complacency, get-home-itis, loss of situational awareness, hazardous attitudes, and misplaced motivation), adverse physical states (fatigue, illness, incapacitation) and physical or mental limitations such as insufficient reaction time and physical or mental incompatibility with the task (Shappell & Wiegmann, 2000). Substandard practices include Crew Resource Management (CRM) issues and personal choices such as self-medicating and violations of bottle to throttle requirements.

Beyond the operator, HFACS examines the supervisory and organizational decisions and practices that prevent or encourage error. Unsafe or inadequate supervision as well as decisions from upper management all play a role in orchestrating the milieu in which errors occur. Reason (1997) insists that oftentimes human error is "more a consequence than a cause" and that "errors are the symptoms that reveal the presence of latent conditions in the system at large" (p. 226).

A common reaction to error is to blame the operator (Reason, 1990, 1997, 2008; Shappell & Wiegmann, 2000). In this way errors are treated as a Human Resources concern; one where individual punishment follows any infraction. "This punitive approach does not solve the problem. People function within systems designed by an organization. An individual may be at fault, but frequently the system is also at fault. Punishing people without changing the system only perpetuates the problem rather than solving it" (Boysen, 2013, p. 400). HFACS highlights the role supervisors and upper management have in error genesis.

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Table 2

Unsafe Supervision

Act	Examples
Inadequate Supervision	Failed to provide guidance Failed to provide oversight Failed to provide training Failed to track qualifications Failed to track performance
Planned Inappropriate Operations	Failed to provide correct data Improper staffing Mission not in accordance with rules and regulations Inadequate crew rest
Failed to Correct a Known Problem	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

Adapted from (Shappell & Wiegmann, 2000, p. 10)

Methods

HEMS accident data from calendar years 2000-2016 were obtained from the NTSB's Aviation Accident Database. The search criteria included any accident that happened during the period in question, involved a non-experimental helicopter, occurred within the United States (no territories), and was on a non-scheduled Part 135 air taxi or commuter flight at the time of the accident. These crashes were then culled to only include those that were engaged in HEMS at the time of the accident.

The NTSB reports two levels of investigation: factual and final. NTSB factual reports detail the events of the accident. This report is typically released within a few days of the event. No attempt is made to delineate the probable cause. The final report not only recounts the factual events of the accident or incident, but attempts to determine, whenever possible, the probable cause of the event. For this research, only accidents which were classified “final” at the time of writing were included. Crashes where the NTSB was unable to find probable cause, or where the primary probable cause was mechanical in nature, were also excluded. While HFACS is well suited for use in maintenance operations, such activity is beyond the scope of this research. In the end, 44 accidents, spanning 17 years, and encompassing 107 separate causal factors were included for evaluation.

Utilizing the NTSB Aviation Accident Final Report as source material, each accident’s causal factors (probable cause) were classified by the author using the HFACS framework. Only those factors identified by the NTSB in the final report were classified. No additional factors were added. To avoid the over-representation of any one HFACS category, each error or violation category was only used once per accident. For example, even though the NTSB statement of probable cause may have included three separate skill-based errors, only one skill-based error was recorded.

Results

Out of the 44 accidents examined, 20 (45%) resulted in fatalities; 36 (80%) involved some type of skill-based error; 18 (41%) decisional error; 23 (52%) perceptual error; seven (16%) exceptional violation; and 23 (52%) supervisory errors.

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Skill-Based Errors

Of the 36 accidents involving skill-based errors, 20 (56%) resulted in fatalities. Every fatal accident in this study involved some type of skill-based error. Tables 3 and 4 detail the identified causes and phase of flight associated with skill-based errors.

Table 3

Causes of Skill-Based Errors

Skill-Based Errors by Cause (*n* = 36)	
Failure to Maintain Control	18 (50%)
Failure to Maintain Clearance	12 (33%)
Equipment Operation	1 (3%)
Failure to Follow Checklist	2 (6%)
Inadequate Visual Lookout	1 (3%)
Excessive Descent Rate	2 (6%)

Table 4

Phase of Flight Skill-Based Errors

Cause by Phase of Flight	Takeoff	Cruise	Landing
Failure to Maintain Control	7	5	6
Failure to Maintain Clearance	2	6	4
Equipment Operation	0	1	0
Failure to Follow Checklist	1	1	0
Inadequate Visual Lookout	1	0	0
Excessive Descent Rate	0	0	2

Decision-Based Errors

Eighteen accidents or incidents involved decision-based errors. Causes identified by the NTSB are listed in Table 5:

Table 5

Decision-Based Errors

Decision-Based Errors by Cause (*n* = 18)	
Aeronautical Decision Making (failure to go around, decision to maneuver in an environment conducive to loss of tail rotor effectiveness, fuel exhaustion, disregard for engine oil warning light, etc.)	10 (56%)
VFR to IMC	6 (34%)
Inadequate Preflight Planning	1 (6%)
Selection of Unsuitable Landing Site	1 (6%)

Of special note: the decision to continue flight into IMC (VFR to IMC) resulted in fatalities in 83% of the accidents examined in this study.

Perception Errors

Faulty perception was cited as a probable cause in 23 (52%) of the accidents and incidents included in this study. Causal factors for these crashes are outlined in Table 6.

Table 6

Perceptual Errors

Perceptual Errors by Cause (*n* = 23)	
Instrument Meteorological Conditions	7 (30%)
Night	7 (30%)
See and Avoid	6 (26%)
Spatial Disorientation	2 (9%)
Brownout	1 (4%)

Supervisory Preconditions and Errors

Supervisory preconditions and errors were listed as a probable cause in 23 of the 44 accidents examined during this study. Issues identified by the NTSB are included in Table 7.

Table 7

Supervisory Errors

Supervisory Preconditions and Errors by Cause (*n* = 23)	
Inadequate Operational Supervision (Lack of Emergency Operations Center or inadequate information from dispatch)	13 (57%)
Inadequate Training	3 (13%)
Failure to Address a Known Problem	2 (9%)
Inadequate Supervision of Maintenance Services	2 (9%)
Inadequate Policies and Procedures	2 (9%)
Not Providing Proper Equipment (Terrain Collision Avoidance Systems)	1 (4%)

Discussion

HEMS' flying is dangerous. Its unique flight profile separates it from other Part 135 operations. However, these conditions alone do not adequately explain the seemingly intractable number of HEMS accidents. This research evaluated 44 HEMS accidents using the HFACS framework to try and better understand these accidents.

Skill-Based Errors

Failure to maintain control of the aircraft was the most common skill-based error found in the present study, followed by failure to maintain clearance—a euphemism for inadvertently hitting an object during flight. Occurrences of skill-based error happened most often during takeoff and landing, when becoming distracted, or forgetting a checklist item are the most dangerous.

Flights involving failure to maintain control were, invariably, the result of an untoward event which caused the pilot to lose control of the aircraft. Loss of tail rotor effectiveness was cited in three reports (NTSB, 2005, 2007b, 2014) and inadequate preflight planning was listed as a causal factor in four of the skill-based accidents (NTSB, 2000a, 2004a, 2008a, 2008b). In one case (NTSB, 2012b), the pilot lost control of the aircraft while attempting to engage the autopilot while transitioning from VFR to an IFR flight profile. In another, the NTSB lists the probable cause as “The pilot's failure to maintain control of the helicopter as a result of his continued flight into known adverse weather conditions. Factors were the dark night light condition, fog, low ceiling, and the pilot's lack of total instrument flight time” (NTSB, 2000b).

It is important to note that a frequent concomitant causal factor was perceptual errors. These errors most commonly involved some degree of spatial disorientation, or the failure to perceive and arrest an unsafe descent rate. One accident outside of El Paso, Texas in 2010 involved a pilot on his second flight with that company, and it was the pilot’s first flight uninstructed using Night Vision Goggles (NVG). The accident occurred on a dark, moonless night with very little cultural lighting. The NTSB attributed the accident to the pilot’s failure to recognize the aircraft’s sink rate or bank angle prior to impact. All three occupants perished. In addition to these findings, the NTSB faulted the company for inadequate training and supervision (NTSB, 2011).

Decision-Based Errors

One perplexing finding is the large number of decisional errors found in the present research. In order to fly HEMS, the minimum requirement is a Commercial Pilot Certificate and approximately 1,500-2,000 flight hours on average (Commission on Accreditation of Medical Transport Systems [CAMTS], 2015). The HEMS flight environment is also highly regulated and ritualized, with numerous regulatory safeguards put in place over the preceding 20 years in an attempt to improve the accident rate (Public Hearing Helicopter Emergency Medical Services, 2009). Despite these efforts, decision-based errors were present in 41% of HEMS accidents in this study.

The most common decision-based errors were associated with faulty Aeronautical Decision Making (ADM), followed by continued flight into Instrument Meteorological Conditions (IMC). Issues identified as faulty ADM by the NTSB included the failure to initiate a go around, the decision to maneuver in an environment conducive to loss of tail rotor effectiveness, fuel exhaustion, and disregarding engine warning lights. Previous research identified the major causes of HEMS accidents as “flying at night, inadvertent flight into IMC, and CFIT” (Public Hearing Helicopter Emergency Medical Services, 2009, p. 23).

Decision-based errors continue to be a perennial and intractable problem; that begs an easy answer. What is certain is that these errors are deadly. In this study, out of the 18 accidents with a decision-error component, 12 (66%) resulted in fatalities, including five out of the six accidents that involved inadvertent flight into IMC.

Perception-Based Errors

Errors of perception were present in 52% of the accidents in this study. These errors are not the result of altered perception per se, but the faulty decision-making process that is the result of unreliable sensations. IMC and night were the two most common cited causes of perceptual errors in this study. This is consistent with the previous NTSB research cited above (Public Hearing Helicopter Emergency Medical Services, 2009). Failure to see and avoid collision were identified as a causal factor in one-quarter (six out of 23) of the accidents reviewed in this study.

Included in this category is one instance of mid-air collision. This accident was counted as two separate accidents, since this is how it was recorded in the NTSB database. In each case, the findings were identical: both helicopter pilots’ failure to see and avoid the other helicopter on approach to the helipad. Contributing factors were both pilots' failure to follow normal arrival and communication procedures (NTSB, 2008c, 2008d).

Supervisory Preconditions and Errors

Organizational and supervisory influences are often overlooked when examining accidents. A common reaction is to simply stop looking for causes after an initial, plausible explanation is found. This lack of rigor is not helpful and allows dangerous preconditions to persist. In this study, supervisory preconditions or errors were identified in 52% (23/44) of the accidents. The most common precondition cited as a probable cause was lack of operational supervision; specifically, the lack of an Emergency Operations Center (EOC) and/or inadequate information from dispatchers.

This point is illustrated by the example at the introduction to this study (NTSB, 2013). Even though the pilot was in constant and continued communication with dispatch, no supervisory input was given regarding the advisability of taking off with a patient on board and inadequate fuel reserves. Had an EOC been in place to advise or prevent the pilot from flying until the aircraft was fueled, this accident may not have occurred.

Similarly, in 2004 a pilot flew into a stand of trees during night operations with fog, killing everyone on board. Unbeknownst to the air medical flight crew, "three other EMS helicopter operators had turned down the mission, including one who had attempted it but had to return because of fog conditions." The NTSB documented that "the accident pilot was not informed that other pilots had declined the mission because of fog." In its final report, the NTSB faulted the operator for "inadequate weather and dispatch information relayed to the pilot" (NTSB, 2004a).

In this study, inadequate training and failure to address known problems were documented by the NTSB as contributing factors in five accidents (NTSB, 2002, 2006a, 2010, 2011, 2012a). This number is likely very low. As detailed previously, there were three skill-based error accidents attributed to loss of tail rotor effectiveness (NTSB, 2005, 2007b, 2014). Was there a training component to these accidents? The NTSB did not list training as a probable cause, so they were not recorded as such in this study. That said, by definition, skill-based errors are those that are due in part to lack of "stick and rudder" flying skills. These problems are addressed with additional training. Likewise, accidents which had factors such as the selection of an unsuitable landing site (NTSB, 2001), failure to maintain rotor RPM during aborted takeoff (NTSB, 2004b), or the failure to execute a go around (NTSB, 2007a) are all problems that beg the question of training.

Conclusion

HEMS is among the most dangerous types of flying in commercial aviation today (FAA, 2010). Its distinctive flight profile makes it unique among FAR Part 135 operations. This research used the HFACS framework to analyze HEMS accidents from 2000-2016. In this study, skill-based errors accounted for the majority of HEMS accidents. This is consistent with previous research conducted by the NTSB. Of particular note was the frequency of supervisory preconditions and errors documented. This area is often overlooked or minimized during accident investigations. The data gathered during this study clearly shows the impact of organizational decisions on safety.

The HFACS framework is an accepted methodology classifying causal factors. This research adds to the body of knowledge regarding HEMS accidents and provides a starting point for further research, specifically trending the data in an attempt to determine if the numerous safety measures adopted by the industry are having the desired effect.

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