USAARL-TECH-TR--2024-25

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Human Factors Analysis and Classification System as a Potential Confounder in Army Aviation Mishap Analysis

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
07-05-2024	Technical Report	

4. TITLE AND SUBTITLE

Human Factors Analysis and Classification System as a Potential Confounder in Army Aviation Mishap Analysis

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Curry, I.[1], & Lee, A.[2]

5d. PROJECT NUMBER

2022-020

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Novosel, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL-TECH-TR--2024-25

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Development Command
Military Operational Medicine Research Program
504 Scott Street
Fort Detrick, MD 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

USAMRDC MOMRP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

[1]United States Army Aeromedical Research Laboratory; [2]United States Army Department of Aviation Medicine

14. ABSTRACT

Introduction: The U.S. Department of Defense has utilized the Human Factors Analysis and Classification System (HFACS) in its various iterations since 2004 to classify and codify the causation of military mishaps. The purpose of this study is to examine the likely accuracy of the HFACS coding of U.S. Army Aviation mishaps.

Methods: The U.S Army Combat Readiness Center (CRC) database was queried for the fiscal years (FY) 2012-2022, the class A and B aviation mishaps were collated with their associated HFACS codes, and the mishap narratives were examined by an expert panel of senior mishap investigators, aviators, and aeromedical practitioners. The resultant disparities between the CRC coding and the assessed causative factors with special reference to spatial disorientation (SD) were then examined.

Results: In the period under examination (FY 2012-2022) there were 184 class A and B helicopter mishaps recorded in the CRC database. Of those, 106 had HFACS version 7.0 codes assigned to them with 52 unique codes used. With specific reference to SD causation, only 3 of the 7 SD-related codes in HFACS version 7.0 were found to have been used; misinterpretation of instruments, misperception of changing environment, and SD. Combined, these amounted to 36 of the 537 codes used (6.7%). The expert analysis of the 106 mishaps coded showed 58 with no SD component (54.7%), 29 with SD as a contributory factor (27.4%), and 25 where SD was assessed as being causal (23.6%). By contrast, the HFACS coded SD causation in 4 of 106 (3.8%) mishaps.

Discussion: The review of CRC codes versus expert opinion suggests that the coding does include elements that are very common in SD mishaps but without the final step to assign an SD code to a specific mishap. Thus, the information being presented to Army aviation senior leadership is providing at best, an incomplete picture and at worst, a significant distortion of mishap causation. This erroneous information may have significant implications for policy making and is particularly dangerous in view of the Future Vertical Lift program currently underway in the U.S Department of Defense.

15. SUBJECT TERMS

Human Factors Analysis and Classification System

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	10	Loraine St. Onge, PhD
					19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Acknowledgements

This research was supported significantly by the U.S. Army Combat Readiness Center personnel, Mike Reed, Charles Flores, Sarah Oldfield, Christopher Acord, and CW5 Johnston who provided analytical and data support.

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Table of Contents

List of Tables

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Introduction

Despite advancements in technology, human error continues to plague both military and civilian aviation. Analysis indicates that human error is identified as a causal factor in 80 to 90 percent (%) of all mishaps and is therefore the single greatest mishap hazard (Wiegmann & Shappell, 2006; National Highway Traffic Safety Administration, 2015). In 2003, the Secretary of Defense established the Department of Defense (DoD) Safety Oversight Council in response to the rising rates of preventable mishaps. Furthermore, the Aviation Safety Improvement Task Force (ASI-TF) was formed to tackle the aviation side of preventable mishaps. The ASI-TF, in turn, established the Human Factors Working Group (HFWG) with a charter to generate human factors and human performance safety strategies designed to identify hazards, mitigate risk, and reduce aviation mishaps throughout the DoD. In 2004, the ASI-TF published the first version of the DoD Human Factors Analysis and Classification System (HFACS), a framework to organize and tabulate human factors cited in safety systems (HFACS Inc., 2022).

Initially developed for the U.S. Navy and the Marine Corps as a mishap investigation and data analysis tool, HFACS is heavily based on the Swiss cheese model of accident causation (Reason, 1990). In 2005, at the request of the Joint Service Safety Council (JSSC), the uniformed services signed a memorandum of agreement (MOA) to codify uniform collection and analysis of human factors data (Joint Services Safety Council, 2005).

The U.S. Army, along with the other services, adopted the DoD HFACS 6.02 guide when it was released in 2006 (Department of the Army, 2022). However, this version of HFACS was aviation-centric and developed for use by human factors subject matter experts (SMEs) such as psychologists and physiologists. Thus, in response to the 2011 DoD Instruction 6055.07 that mandated DoD components use a common human error categorization system, the JSSC HFWG released the HFACS version 7.0 that was more inclusive of non-aviation communities, and was the shared taxonomy used across the services for organizing and tabulating human factors cited by the JSSC (JSSC HFWG Charter, Nov 19). In June 2022, the JSSC approved the DoD HFACS version 8.0 that was designed to be more user friendly for all safety officers.

An emerging issue for organizations that base policy for flight safety on the output created by HFACS coding of mishaps, is the suspicion that causative and contributory factors are being incorrectly coded. The three versions of HFACS over the 17 years of its military use have potentially confused conclusions from mishap investigations over the years leading to them being erroneous.

In 2012, Gaydos et al. reported a mishap series from the U.S. Army Combat Readiness Center (USACRC) database which concluded that 11% of class A through C mishaps over a 10-year period involved spatial disorientation (SD). This figure seemed to be somewhat anomalous in terms of the historic data regarding SD involvement in mishap causation; indeed, the authors expressed caution about the potential confounders in this finding. Multiple authors over many years, to include Braithwaite et al. (1997), Bushby (2005), and Curry & McGhee (2007), along with many others (Gibb et al., 2011; Mortimer, 1995; Previc & Ercoline, 2004) have found a significantly higher rate of SD mishap causation; consistently at around 30 to 35% with excursions of up to 50% in the early period of desert deployments. The main difference in these studies was that the authors used SME panels to assess mishap investigations and assign causation. The purpose of this study was to examine the USACRC HFACS coded mishap causation in a time series in contrast to an SME examination of the same series, specifically with reference to SD. The varying SD-related HFACS code elements are summarized in Table 1.

Table 1. HFACS SD Codes

HFACS version	**SD related codes**
6.02	**PC501 Illusion – Kinesthetic** Illusion – Kinesthetic is a factor when somatosensory stimuli of the ligaments, muscles, or joints cause the individual to have an erroneous perception of orientation, motion or acceleration leading to degraded performance. (If this illusion leads to spatial disorientation, you must mark and rate PC508, PC509 or PC510.) **PC502 Illusion – Vestibular** Illusion – Vestibular is a factor when stimuli acting on the semicircular ducts or otolith organs of the vestibular apparatus cause the individual to have an erroneous perception of orientation, motion or acceleration leading to degraded performance. (If this illusion leads to spatial disorientation, you must mark and rate PC508, PC509 or PC510.) **PC503 Illusion – Visual** Illusion – Visual is a factor when visual stimuli result in an erroneous perception of orientation, motion or acceleration, leading to degraded performance. (If this illusion leads to spatial disorientation, you must mark and rate PC508, PC509 or PC510.) **PC504 Misperception of Operational Conditions** Misperception of Operational Conditions is a factor when an individual misperceives or misjudges altitude, separation, speed, closure rate, road/sea conditions, aircraft/vehicle location within the performance envelope or other operational conditions and this leads to an unsafe situation. **PC505 Misinterpreted/Misread Instrument** Misinterpreted/Misread Instrument is a factor when the individual is presented with a correct instrument reading, but its significance is not recognized, it is misread or is misinterpreted. **PC506 Expectancy** Expectancy is a factor when the individuals expect to perceive a certain reality and those expectations are strong enough to create a *false perception* of the expectation. **PC507 Auditory Cues** Auditory Cues is a factor when the auditory inputs are correctly interpreted but are misleading or disorienting. Also, when the inputs are incorrectly interpreted and cause an impairment of normal performance.

	PC508 Spatial Disorientation (Type 1) Unrecognized Spatial Disorientation is a failure to correctly sense a position, motion, or attitude of the aircraft or of oneself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. Spatial Disorientation (Type 1) Unrecognized is a factor when a person's cognitive awareness of one or more of the following varies from reality: attitude; position; velocity; direction of motion or acceleration. Proper control inputs are not made because the need is unknown. **PC509 Spatial Disorientation (Type 2) Recognized** Spatial Disorientation is a failure to correctly sense a position, motion, or attitude of the aircraft or of oneself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. Spatial Disorientation (Type 2) is a factor when recognized perceptual confusion is induced through one or more of the following senses: visual; vestibular; auditory; tactile; proprioception or kinesthetic. Proper control inputs are still possible. **PC510 Spatial Disorientation (Type 3) Incapacitating** Spatial Disorientation is a failure to correctly sense a position, motion, or attitude of the aircraft or of oneself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. Spatial Disorientation (Type 3) Incapacitating is a factor when an individual is unable to make proper control inputs for safe operation of the aircraft or system due to a conflict (often extreme) between the sensory systems identified in Type 2.
7.0	**PC501 Motion Illusion – Kinesthetic** Motion Illusion – Kinesthetic is a factor when physical sensations of the ligaments, muscles or joints cause the individual to have an erroneous perception of orientation, motion, or acceleration. (If this illusion leads to spatial disorientation, you must code PC508.) **PC502 Turning/Balance Illusion – Vestibular** Turning/Balance/Illusion – Vestibular is a factor when stimuli acting on the balance organs in the middle ear cause the individual to have an erroneous perception of orientation, motion, or acceleration. (If this illusion leads to spatial disorientation, you must code PC508.) **PC503 Visual Illusion** Visual Illusion is a factor when visual stimuli result in an erroneous perception of orientation, motion, or acceleration. (If this illusion leads to spatial disorientation, you must code PC508.) **PC504 Misperception of Changing Environment** Misperception of Changing Environment is a factor when an individual misperceives or misjudges altitude, separation, speed, closure rate, road/sea conditions, aircraft/vehicle location within the performance envelope or other operational conditions.

	PC505 Misinterpreted/Misread Instrument Misinterpreted/Misread Instrument is a factor when the individual is presented with a correct instrument reading, but its significance is not recognized, it is misread or is misinterpreted. **PC507 Misinterpretation of Auditory/Sound Cues** Misinterpretation of Auditory/Sound Cues is a factor when the auditory inputs are correctly interpreted but are misleading/disorienting or, when the inputs are incorrectly interpreted and cause an impairment of normal performance. **PC508 Spatial Disorientation** Spatial Disorientation is a factor when an individual fails to correctly sense a position, motion, or attitude of the aircraft/vehicle/vessel or of oneself. Spatial Disorientation may be unrecognized and/or result in partial or total incapacitation.
8.0	**PC321 Spatial Disorientation** Spatial Disorientation is when the individual failed to correctly sense a position, motion, or attitude of the aircraft or his/herself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical position (e.g., visual, vestibular, kinesthetic, or auditory/sound illusions), which resulted in a misjudgment and unsafe act.

The table shows the evolution of HFACS versions, with 10 SD-related codes in version 6.02, 7 in version 7.0, and only 1 in version 8.0. The mishap series in this investigation is all coded in version 7.0 and, although simpler than the very aviation-oriented version 6.02, still assumes a certain level of technical, perceptual, and physiological familiarity by the coder. The initial taxonomy (version 6.02) was based heavily on jets. Version 7.0 expanded this category to prop fixed-wing. When the HFWG was developing version 8.0, they questioned how these codes were used across the services and if these codes could be condensed into one, as all are a form of “disorientation.” Data pulls from the U.S. Air Force, the U.S. Navy, and U.S. Marine Corps demonstrated that those who were using the various SD-related codes (physiologists) could not agree on the level or type of SD. They could only agree there was a probable form of SD. To reduce the inconsistencies of application by the HFACS SMEs (physiologists & psychologists), the version 8.0 HFWG recommended to omit the level of granularity and collapse all SD-related codes into one code (PC321) and place it into its proper subcategory of "adverse physiological condition" (USACRC, personal communication, March 14, 2024) .

Methods

The USACRC mishap database was queried for class A and B aviation mishaps over the fiscal year (FY) period FY 2012-2022. The rationale for choosing class A and B only was twofold. Most previous papers have considered these classifications, and the number of mishaps to examine becomes unmanageably large for an SME panel if class C mishaps are included. The USACRC mishap definitions are detailed in Table 2.

Table 2. Mishap Classification

Mishap class	Definition
A	An Army mishap in which the resulting total cost of property damage is $2,500,000 or more; an Army manned aircraft is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.
B	An Army mishap in which the resulting total cost of property damage is $600,000 or more, but less than $2,500,000; an injury and/or occupational illness results in permanent partial disability, or when 3 or more personnel are hospitalized as inpatients as the result of a single occurrence.
C	An Army mishap in which the resulting total cost of property damage is $60,000 or more, but less than $600,000; a nonfatal injury or occupational illness that causes 1 or more days away from work or training beyond the day or shift on which it occurred or disability at any time (that does not meet the definition of Class A or B and is a lost time case).
D	An Army mishap in which the resulting total cost of property damage is $25,000 or more, but less than $60,000; a nonfatal injury or illness resulting in restricted work, transfer to another job, medical treatment greater than first aid.
E	An Army mishap in which the resulting total cost of property damage is $5,000 or more but less than $25,000.

The mishaps were assessed independently by six members of an expert panel consisting of senior mishap investigators, aviators, and aeromedical practitioners. The panel utilized the internationally recognized definition of SD, that of Benson (2002): ‘Aviation-associated spatial disorientation occurs when the pilot fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical.’ The definition excludes getting lost but does include striking an object the pilot knew to be present. The panel was asked to read the mishap narratives and then to independently grade each as ‘no SD,’ ‘SD contributory,’ or ‘SD causal.’ These gradings were then discussed if there was more than one dissenter to a particular determination on a given mishap. This dissent resolution occurred in 34 of the 184 cases (approximately 18% of the cases). The expert assessments were then overlaid on the USACRC HFACS codes for those mishaps to determine the level of agreement with the database.

Results

In the period under examination (FY 2012-2022) there were 184 class A and B helicopter mishaps recorded in the USACRC database. Of those, 106 had HFACS version 7.0 codes assigned to them with 52 unique codes used. This discrepancy is largely due to the policy that less serious mishaps are investigated locally and often do not have codes assigned, thus the 106 represent the more serious end of the spectrum. These 106 mishaps produced 537 codes. There was a mean of 5 codes per mishap and each mishap was coded with between 1 and 9 codes. Generally, the more complex the cause of the mishap was assessed to be, the more codes that were assigned.

With specific reference to SD causation, only 3 of the 7 SD-related codes in HFACS version 7.0 were found to have been used; those were misinterpretation of instruments, misperception of changing environment, and SD. Combined, these amounted to 36 of the 537 codes used in the 106 mishaps coded (6.7%).

The expert analysis of the 106 mishaps coded showed that 58 had no SD component (54.7%), 29 had SD as a contributory factor (27.4%), and 25 were assessed as SD being causal (23.6%). By contrast, the HFACS coding indicated that only 4 of 106 (3.8%) mishaps had SD as a causal factor. The expert-assessed figures are consistent with other longitudinal studies of rotary-wing (RW) mishap causation and imply that the recorded HFACS data seriously underrepresents the toll that SD has on the U.S. Army RW fleet. The most used HFACS codes with assessed SD contribution are detailed in Table 3 below.

Table 3. Top 12 HFACS Codes in Relation to Assessed SD Contribution

HFACS code	**No SD**	**SD contributory**	**SD causal**	**Percentage of code where SD was a factor (%)**
Environmental conditions affecting visibility	15	13	17	67
Failed to effectively communicate	20	18	12	60
Overconfidence	20	18	12	60
Complacency	15	13	10	60
Procedure not followed correctly	24	7	8	38
Critical information not communicated	13	16	6	63
Over controlled/under controlled aircraft	17	4	6	37
Misperception of changing environment	13	13	5	58
Breakdown in visual scan	4	17	4	84
Selected individual with lack of current/limited experience	4	4	4	67
Spatial disorientation	0	0	4	100
Supervisory/command oversight inadequate	9	9	4	59

Discussion

In Table 3, the twelve most used HFACS codes in this mishap series are divided out by how often they were mentioned in relation to the expert assessments of SD contribution. The percentage of code use where SD was determined to be a factor is illuminating in that the HFACS codes represent situations where RW SD occurs. Braithwaite et al. (1997) showed that the typical RW SD mishap is not related to a classical illusion scenario, but almost universally to a combination of loss of visual reference, distraction, and inattention. The codes previously shown in Table 3 reference changing visibility, visual scan breakdown, misperception of the environment, and complacency. All of these would fit into the now accepted mode of RW SD causation and it could be argued that other high scorers such as miscommunication, overcontrolling, and inexperience/un-currency are also common factors in the investigation of SD mishaps.

Thus, the USACRC mishap coding is examining the correct factors, just failing to make the final determination of SD involvement. This may be due to a lack of understanding of the definition of SD* but also of the more recent research into the actual causation of most SD mishaps in RW aviation. This may be a function of the Army's methodology for conducting mishap investigations, which is a two-tiered system. Centralized Accident Investigation (CAI) and Installation Accident Investigation (IAI) are two different types of investigations. The CAI receives greater scrutiny as the report is compiled, while in the IAI reports that the code selection is completed by the external mishap board. In neither case, unlike the U.S. Navy and U.S. Air Force, are specialist human factors personnel involved in the process, a potential source of error when considering human factors elements in Army mishaps. An effort to alleviate this has been initiated with the fielding of the Army Safety Information Management System (ASIMS); the USACRC recognized a training gap for all military safety officers and civilian safety and occupational health professionals. To reduce the HFACS application training gap, the USACRC incorporated improved HFACS analysis case studies into the Army Mishap Investigation Course (AMIC) in 2020, which is presented to Army uniformed safety officers and civilian safety and occupational health professionals. Lastly, the USACRC released a series of HFACS training tutorials. These interactive tutorials are targeted at safety personnel to enhance application of the HFACS taxonomy to both mishaps and hazard inspections captured in the ASIMS tool. In the HFACS versions 6.02 and 7.0, the codes within the SD umbrella were biased toward visual, vestibular, and kinesthetic illusions. This is understandable given the origin of the system and the original intent, to investigate aviation mishaps with a significant bias toward the fast-jet community.

Conclusion

The situation as it stands now is that the Army's HFACS coding is significantly understating the contribution of SD to loss of aviators and aircraft. SD mishaps are more lethal than others (Curry & McGhee, 2007; Mortimer, 1995; Previc & Ercoline, 2004) and therefore contribute disproportionately to the human toll of Army mishaps. If this underemphasis of SD mishap causation is being used to inform senior leaders' policy decisions then there is a

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*The U.S. Army defines spatial disorientation as "an individual's inability to determine his or her position, attitude, or motion relative to the Earth's surface."

significant problem, and one that could compound as new and more advanced aircraft enter service.

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