USAARL Report No. 2013-01

Ten Years of Spatial Disorientation in U.S. Army Rotary-Wing Operations (Reprint)

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October 2012

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
23-10-2012	Final	2011-2012

4. TITLE AND SUBTITLE
Ten Years of Spatial Disorientation in U.S. Army Rotary-Wing Operations (Reprint)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Steven J. Gaydos
Michael J. Harrigan
Alaistair J. R. Bushby

5d. PROJECT NUMBER

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 Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2013-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Combat Readiness/Safety Center
BLDG 4905, 5th Avenue
Fort Rucker, AL 36362

10. SPONSOR/MONITOR'S ACRONYM(S)
USACR/SC

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

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Aviation, Space, and Environmental Medicine, volume 83, number 8, page 739-745, August 2012

14. ABSTRACT
Spatial disorientation (SD) has plagued aviation since its inception, contributing to numerous lost lives, destroyed or damaged aircraft, and a reduction in operational mission effectiveness. Military rotary-wing (RW) operations are not immune. The U.S. Army has retired many “legacy aircraft” represented in older studies, developed new training regimens for aircrew, continued to expand its night vision capabilities, and has prosecuted combat operations for some 10 yr utilizing new tactics, techniques, and procedures. BFor these reasons, it is important and relevant to re-engage the subject of SD among accidents within the Army’s RW community. The U.S. Army's Combat Readiness/Safety Center database at Fort Rucker, AL, was queried for the previous 10 yr RW mishaps from fiscal year (FY) 2002 through FY 2011 (FY11 current through 01 July). Accidents identified as having SD as a contributing factor were selected. From FY 2002 to FY 2011, there were 100 Class A through C rotary-wing flight mishaps involving SD. This represents 11% of all Class A through C rotary-wing flight accidents for this period. Of the 100 SD-related accidents, 22% involved

15. SUBJECT TERMS
spatial disorientation, aircraft accidents, aircraft mishaps, rotary-wing, helicopter

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	7	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Standard Form 298 (Rev. 8/98)
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fatalities, and 39% involved fatalities and/or injuries. The total number of RW SD-related accidents with fatalities represents 31% of the total helicopter accidents with fatalities for the 10-yr period. This review of accident data confirms that SD remains a substantial issue for the Army aviation community and reinforces the importance and relevance of SD awareness, research, education, and training in RW operations.

Ten Years of Spatial Disorientation in U.S. Army Rotary-Wing Operations

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Gaydos SJ, Harrigan MJ, Bushby AJR. ***Ten years of spatial disorientation in U.S. Army rotary-wing operations.*** **Aviat Space Environ Med 2012; 83:739–45.**

Introduction: Spatial disorientation (SD) has plagued aviation since its inception, contributing to numerous lost lives, destroyed or damaged aircraft, and a reduction in operational mission effectiveness. Military rotary-wing (RW) operations are not immune. The U.S. Army has retired many "legacy aircraft" represented in older studies, developed new training regimens for aircrew, continued to expand its night vision capabilities, and has prosecuted combat operations for some 10 yr utilizing new tactics, techniques, and procedures. For these reasons, it is important and relevant to re-engage the subject of SD among accidents within the Army's RW community. ***Methods:*** The U.S. Army's Combat Readiness/Safety Center database at Fort Rucker, AL, was queried for the previous 10 yr RW mishaps from fiscal year (FY) 2002 through FY 2011 (FY11 current through 01 July). Accidents identified as having SD as a contributing factor were selected. ***Results:*** From FY 2002 to FY 2011, there were 100 Class A through C rotary-wing flight mishaps involving SD. This represents 11% of all Class A through C rotary-wing flight accidents for this period. Of the 100 SD-related accidents, 22% involved fatalities, and 39% involved fatalities and/or injuries. The total number of RW SD-related accidents with fatalities represents 31% of the total helicopter accidents with fatalities for the 10-yr period. ***Discussion:*** This review of accident data confirms that SD remains a substantial issue for the Army aviation community and reinforces the importance and relevance of SD awareness, research, education, and training in RW operations.

Keywords: spatial disorientation, aircraft accidents, aircraft mishaps, rotary-wing, helicopter.

DESPITE THE EXTRAORDINARY rate of technological advances in aviation-related sciences and aircraft vehicle development over the past 100 yr, the human pilot ostensibly remains version 1.0, evolved for a terrestrial life at 1 G directed toward the Earth's center. A pilot's ability to accurately perceive his orientation and movement in space with respect to the Earth is essential for effective piloting and safe aircraft operation, yet we are in many ways poorly physiologically equipped to deal with the dynamic flight environment. As a result, spatial disorientation (SD) has plagued aviation since its inception, contributing to numerous lost lives, destroyed or damaged aircraft, and a reduction in operational mission effectiveness. Indeed, almost 100 yr ago, Royal Navy Surgeon-Lieutenant H. Graeme Anderson (1) astutely noted that "…a sound equilibrium and muscle sense is essential in flying, so that the aviator would be conscious of his position in space, realize at once any deviations therefrom, and correct these quickly. But in fog it has been found almost impossible to detect any deviation during a flight. Time and again aviators coming out of dark clouds or fog have found themselves flying one wing down, and it has been recorded that some have flown upside down without knowing it" (p. 33).

Parmet and Ercoline (22) define SD as "a state characterized by an erroneous orientational percept, that is, an erroneous sense of one's position and motion relative to the plane of the Earth's surface" (p. 181). Despite decades of awareness to this killer within the aviation community, SD-related accident rates have not declined substantially over the years, contributing to approximately one-third of all mishaps (16). SD accidents are particularly unforgiving, with very high rates of pilot and crew fatalities in both the military and general aviation arenas (16,20,23).

The U.S. Army (11) defines spatial disorientation as "an individual's inability to determine his or her position, attitude, and motion relative to the Earth's surface" (p. 9-1). There have been previous major reviews of U.S. Army rotary-wing (RW) mishaps with respect to SD with varying results and confounding comparisons by differing definitions, predominant aircraft of the time, and changes over time in training, tactics, and technology [e.g., night vision goggles (NVG) and forward looking infrared (FLIR) night vision systems]. Ogden and colleagues (21) provided one of the first looks (1957 to 1963) at Army helicopter "orientation error" (OE), reporting that it accounted for only 3.4% of major accidents, but 30.7% of all accident fatalities. Hixson and Spezia (17) reported over a 5-yr period (1967 to 1971) that OE accounted for 7.4% of total accidents and 16.5% of the total number of fatal accidents. Vyrnwy-Jones (25) analyzed data from U.S. Army helicopter SD accidents from 1980 to 1987, reporting $< 1\%$ of accidents attributable to OE, but responsible for one-quarter of severe accidents (Class A and B) and 14.8% of fatalities. In 1995,

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This manuscript was received for review in September 2011. It was accepted for publication in March 2012.

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DOI: 10.3357/ASEM.3196.2012

Durnford and colleagues (13) determined that 32% of accidents from 1987 to 1992 were considered to have involved SD. In this case, the authors particularly noted the high SD accident risk of flying at night and with night vision systems. Braithwaite and colleagues (4,6) extended this work to include the years 1993 to 1995, confirming that approximately 30% of accidents had SD as a major or contributing factor.

To adduce further evidence of the impact of SD on RW accidents, in the 1987 to 1995 data sets, SD-related mishaps constituted a larger percentage of Class A accidents, had higher average cost associated per accident, and resulted in more total lives lost and average lives lost per accident than non-SD-related accidents (6). Since the previous reviews, the Army has retired many "legacy aircraft" represented in older studies, developed new training regimens for aircrew, continued to expand its night vision capabilities, and has prosecuted combat operations for some 10 yr exploiting new tactics, techniques, and procedures. For these reasons, it is important and relevant to re-engage the subject of SD among accidents within the Army's RW community.

METHODS

The U.S. Army's Combat Readiness/Safety Center database at Fort Rucker, AL, was queried for the previous 10 yr helicopter mishaps from fiscal year (FY) 2002 through FY 2011 (FY 11 data current through 01 July). Each FY included the period from 01 October of the previous calendar year through 30 September of that calendar year. RW mishaps implicating SD as a contributing factor were selected as cases for analysis. Cases were identified as codified by the Combat Readiness/Safety Center based on the Army definition.

U.S. Army schema for accident classification is listed in **Table I**. Accident data do not include mishaps secondary to combat or hostile action. Combat or hostile action includes: enemy action, evasive action taken to avoid enemy fire, or losses when returning from a combat mission when the last known position was in or over enemy territory (12). Accident classes A through C were included in the review and analysis.

RESULTS

For FY 2002 to FY 2011 (inclusive to 01 July 2011), there were 100 Class A through C rotary-wing flight mishaps involving SD. This represents 11% of all Class A through C rotary-wing flight accidents for this period. Of the 100 SD-related accidents, 22% involved fatalities and 39% involved fatalities and/or injuries. The total number of rotary-wing SD-related accidents with fatalities represents 31% of the total helicopter accidents with fatalities for the 10-yr period. SD-related mishaps were more likely to result in a fatality ($X^2 = 29.24$, $P < 0.0001$) with a risk ratio (RR) of 3.6. In almost half of the cases (44%), there was a total loss of aircraft. Further characteristics of related factors in SD-related Class A through C accidents are presented in **Table II**.

Numbers of SD accidents by year and by airframe are reflected in **Figs. 1 and 2**. Total and SD-related RW mishap rates per 100,000 flying hours are shown in **Fig. 3**, with an average rate of 9.76 for all accidents and 1.06 for SD-related accidents. The Army's current main operational helicopter force is largely comprised of four airframes: UH/MH-60, CH/MH-47, OH-58D, and AH-64. SD-related mishap rates per 100,000 flying hours per airframe per year for these four airframes are reflected in **Fig. 4**. A rate comparison by year of these four main operational aircraft versus all RW aircraft for SD-related accidents is presented in **Fig. 5**. The total SD-related mishap rate (for all eight airframes) and the rate of the four main operational airframes demonstrated a decline over the 10-yr timeframe studied [$r(8) = -0.81$, $P = 0.004$, and $r(4) = -0.79$, $P = 0.006$, respectively].

DISCUSSION

This review of accident data from FY 2002 to FY 2011 confirms that SD remains a substantial issue for the Army RW community (not unlike other U.S. and foreign military services and general aviation). For the 10-yr

TABLE I. CLASSIFICATION OF U.S. ARMY ACCIDENTS (12).

Classification	Description
A	The resulting total cost of property damage is $2 million or more; an Army aircraft is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.
B	The resulting total cost of property damage is $500,000 or more, but less than $2 million; an injury and/or occupational illness results in permanent partial disability, or when three or more personnel are hospitalized as in-patients as the result of a single occurrence.
C	The resulting total cost of property damage is $50,000 or more, but less than $500,000; 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 day(s) away from work case).
D*	The resulting in total cost of property damage is $2000 or more, but less than $50,000; a nonfatal injury or illness resulting in restricted work, transfer to another job, or medical treatment greater than first aid.
E*	The resulting total cost of property damage is less than $2000.
F*	Incidents are confined to aircraft turbine engine damage because of unavoidable internal or external foreign object damage, where that is the only damage.

* Excluded from analysis.

TABLE II. CHARACTERISTICS OF SD-RELATED ROTARY-WING MISHAPS CLASS A-C, U.S. ARMY FY 2002-2011.*

Category	Characteristic	Percent
Type of Operation	Single ship	40
	Multiship	58
	NR	2
Period	Day	30
	Night	66
	Dawn/Dusk	4
Visual Aid	Any	65
	NVG	44
	Integrated NVS	21
Operationally Related	OIF	42
	OEF	18
	Other	2

* FY11 current through 01 July 2011.
NR- not reported; NVG- night vision goggles; NVS- night vision system; OIF- Operation Iraqi Freedom; OEF- Operation Enduring Freedom.

period under review, FY 2003 had the highest number of SD-related mishaps (Fig. 1), while the UH/MH-60 had the most number by aircraft type (Fig. 2). However, disproportionate numbers of hours flown per year and by airframe affect risk exposure so that more accurate comparisons by year and by airframe should be made upon rates (Figs. 3 and 4). SD contributed to, on average, 10 mishaps per year at a rate of 1.1 per 100,000 flying hours for all RW aircraft and 1.4 for main operational aircraft (Fig. 5). SD was implicated in 11% of U.S. Army RW accidents reviewed. Although this is lower than the 30 to 32% reported for the previous decade (4,6,13), some points are noteworthy. Caution should be exercised with direct comparison of previous reviews with respect to confounding issues of case definition and selection, predominant airframes used during the period under review, and changes in training, tactics, techniques, and procedures that evolved over 10 years of war. The issue of case selection is worthy of specific mention. In previous reviews, all mishaps were reviewed by experienced aeromedical specialists with cases implicating SD selected with a high degree of interrater reliability. In the present study, cases were selected as codified by the Combat Readiness/Safety Center. Depending on the mishap specifics, not every aviation Class A-C mishap is required to have a flight surgeon as a member of the investigating board (12) and investigating officials may have varying levels of related expertise in recognizing SD as a contributing factor to the mishap.

Despite reports that overall rates of SD-related mishaps are not decreasing (2,9,16), the data for this period under review do reflect a decreasing accident rate from a high of almost three per 100,000 h in 2003 to lows of less than one from 2006 onward. This may represent a combination of two influential effects: high rates in the early years of combat theater flying and a decline through subsequent successful implementation of SD-mitigation strategies. There has, in fact, been a concerted effort within the military RW community since the previous U.S. Army SD-related mishap reviews that has included triservice and multinational symposia and working groups (2,3,5), research and training developments (7,15,19), and technology initiatives (2,23,24) to address the problem. Clearly, there is more work to be done. It is known that SD-related mishaps often carry a disproportionately higher penalty with respect to severity when compared to non-SD accidents. These data also reinforce this significance and gravity, whereby SD-related mishaps were more likely to result in a fatality, with a RR of 3.6. In addition to almost one-quarter (22%) of SD cases reviewed resulting in fatalities, this is further evidenced by more than one-third (39%) causing fatalities and/or injuries and almost one-half (44%) resulting in total destruction of the airframe.

Furthermore, there is argument that the actual number of SD-related accidents is probably higher than what is truly captured in mishap databases (5,14,16) with issues of inaccurate and under-reporting of SD in accident investigations. Gibb and colleagues (16) cite issues of misapplication of the definition (e.g., "too vestibular-centric"), restrictive classification taxonomies and coding, the fleeting and transitory nature of important SD-related information, and resistance to cite contributing human factors in accident reports (p. 718–719). Considering the extent of the problem, it is also important to note that, as previously reported (2,6,19), the "operational

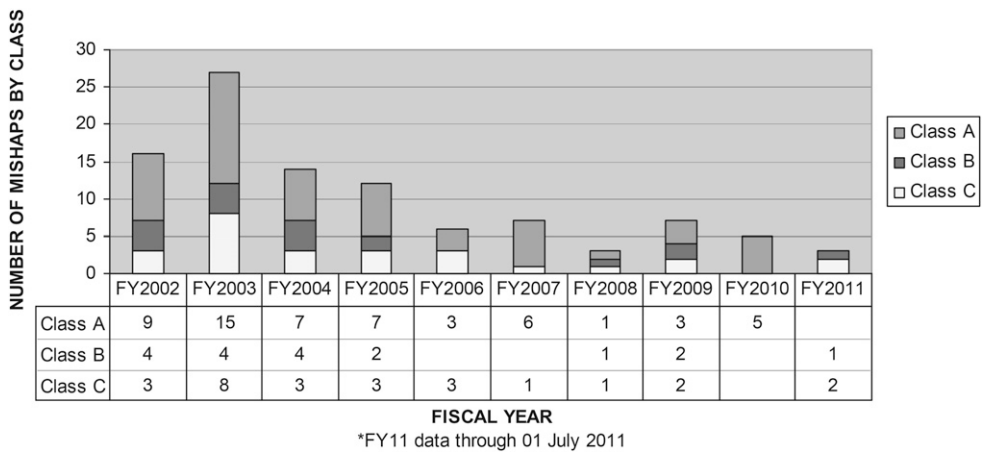

Fig. 1. Spatial disorientation-related rotary-wing mishaps, U.S. Army FY 2002-2011 by FY and Accident Class.

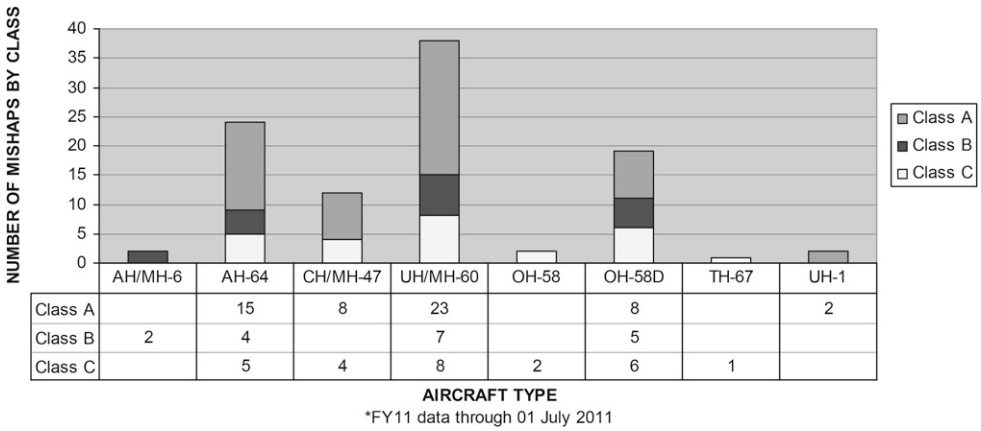

Fig. 2. Spatial disorientation-related rotary-wing mishaps, U.S. Army FY 2002-2011 by aircraft type.

penalty" of SD is not solely limited to losses—few episodes of SD actually result in a mishap. SD-related accident rates imply a much greater impact on crew operational effectiveness due to a significant number of "SD incidents" not captured in accident data. An illustrative quote was delivered at the first Triservice Symposium on Spatial Disorientation in Rotary-Wing Operations (5): "Just because we've not crashed more aircraft is not a reason to disregard SD's importance" (p. 30). These data do not reflect reduced crew efficiency, altered missions, or degraded effectiveness from SD-related "near misses."

The U.S. Army has prosecuted 10 yr of combat operations during the timeframe included in this review. The fact that helicopter SD-related losses are likely to be higher under wartime conditions has been described previously (5,8,10). Case in point is the SD-related mishap peak of FY 2003, coinciding with the commencement of Operation Iraqi Freedom. This likely represents ill-preparation for difficult sand and dust conditions, with the overwhelming majority of SD-related mishaps reviewed from early in that theater involving brownout. The subsequent decline was multifactorial and can be attributed to command redress, more aggressive and extensive training prior to movement into theater, accumulation of aviator experience, and improved landing surfaces (e.g., forward arming and refueling points) as the theater matured.

Many conditions common to combat flight operations for the modern RW military aviator can contribute to SD: task saturation, high workload, cockpit distractions, complex and dynamically evolving missions, stress and anxiety, fatigue, unexpected or deteriorating weather conditions, unusual landing environs, night operations, prevalent employment of night vision systems, and others. These data have borne this out with nearly two-thirds (62%) of SD-related helicopter mishaps resultant from combat theaters (not including enemy action or evasive action taken to avoid enemy fire), more than half (58%) from multiship missions, two-thirds (66%) at night, and close to half (43%) involving brownout (all but two occurring in combat theater).

The association of advanced technology with SD has been described previously (16,18,24). Night vision systems provide a poignant example of technological advances increasing the SD risk. While bringing a potent

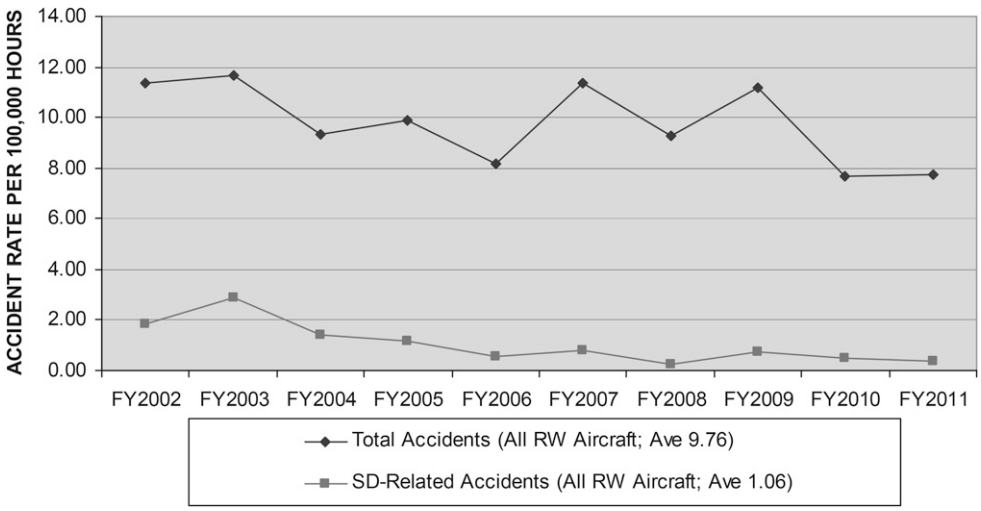

Fig. 3. Rotary-wing mishap rate, U.S. Army FY 2002-2011 (FY 11 data through 01 July 2011).

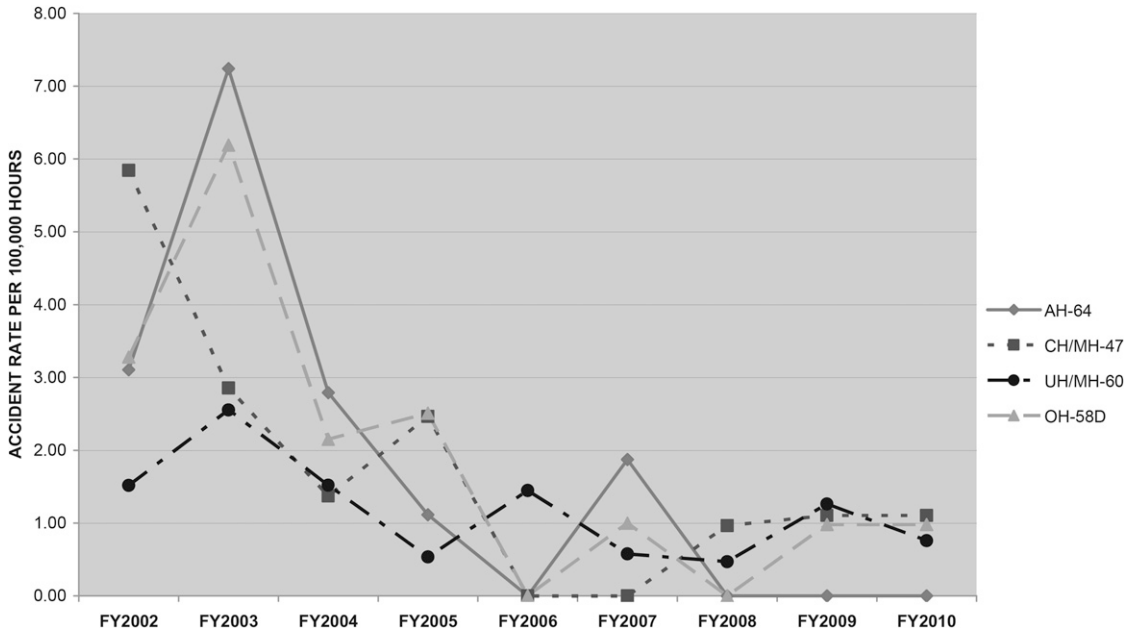

Fig. 4. Spatial disorientation-related rotary-wing mishaps (per 100 K flying hours), U.S. Army FY 2002-2010.

flight and operational capability, NVGs or integrated pilot night vision systems subsume numerous potential contributors to SD: poor contrast, reduced visual acuity, limited field of view, reduced depth cues, increased workload, fatigue, and others. This is likewise reflected in these data with two-thirds (65%) of SD-related helicopter mishaps employing a night vision aid at the time.

Commanders, safety officers, flight surgeons, and aircrew must maintain a healthy respect of, and vigilant posture toward, SD—both in training and especially in combat theaters. It degrades operational effectiveness and remains not only a significant contributor to mishaps, but also a disproportionate player in serious accidents with fatalities and airframe destruction. SD represents an enduring and substantial risk to safe helicopter operations. The myriad challenges facing aviation leaders and commanders include preservation of combat capability and force protection, including the problem of SD. Addressing this issue has generally included the areas of awareness, research, education and training, and technological initiatives. A thorough treatment of this subject is beyond the scope of this discussion. Worth mention, however, is that addressing the problem necessitates the allocation of time, resources, and funding—not unlimited commodities in a milieu of competing priorities and fiscal constraint. Technological initiatives that have received attention include vibrotactile cueing, novel symbology, three-dimensional audio, enhanced night vision systems, auto-recovery systems, and others. Many of these show great promise for certain types of SD-related errors. Caution should be exercised with viewing technology as a panacea, however, with concern

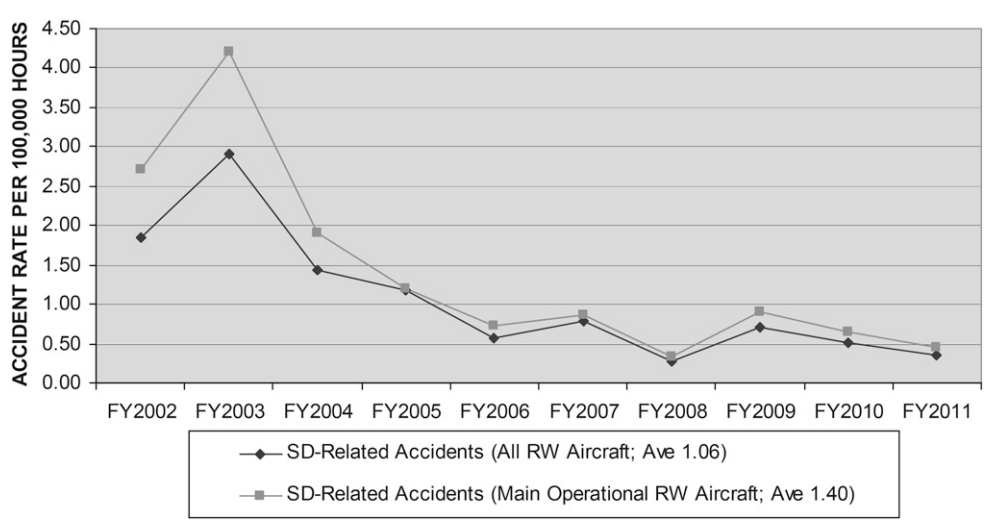

Fig. 5. Spatial disorientation-related rotary-wing mishap rate (per 100 K flying hours), U.S. Army FY 2002-2011 (FY 11 data through 01 July 2011).

that we are simply shifting the over-tasked pilot's fundamental SD-related errors to other categorizations. Awareness has historically fluctuated, often rising to heights during periods marked by losses. SD-related cognizance and emphasis must be included not only in the syllabus of the pilot in training, but should permeate beyond the cockpit into courses for precommand and tactical planning.

Also worth mention is that some solutions may not represent a (comparatively) significant devotion of funding and resources. Braithwaite (5) concluded that "the 'typical' picture of rotary-wing SD is less one of a classical vestibular or visual illusion giving the pilot vertigo, but more one of hard-pressed aircrew flying a systems intensive aircraft using NVDs failing to detect a dangerous flight path" (p. 22). Certainly most, if not all, accidents are multifactorial in etiology, yet often accident board investigations include recommendations well within reach: better allocation of duties among crew, improve crew coordination, fatigue management, refine scan technique, review aeromedical aspects, and promote awareness of risk, as examples. To the extent that these can be addressed through training, as well as how best training should be implemented, is a matter of some dispute, but there has been significant work done to advance the topics of education and training (2,3,23). Triservice, interagency, and multinational work within the fold of training must continue and should include regular symposia reviewing, contrasting, and comparing ground- and flight-based demonstrations, frequency of instruction and requirement of refresher training, as well as audits and validation of effectiveness. Mission, roles, and aircraft differ, but similarities of some airframes and prevalence of common SD-related flight situations and subsequent errors permit exchange of evidence-based knowledge, best practices, and most effective techniques. It is unlikely that resources will permit attack of the problem on all fronts to consummation. Yet this should not preclude the implementation of some solutions where possible. Some may be relatively easier or fiscally permissible to implement and, where it can help, should be readily applied.

The human pilot will likely never be invulnerable to SD. These data represent a favorable decline in SD-related RW mishaps both from the previous decade and during the decade under review with successful SD-mitigation strategies worthy of further investigation. However, this study also confirms that SD remains a substantial issue for the Army RW community and reinforces that SD-related accidents represent disproportionate mishap severity.

ACKNOWLEDGMENTS

The authors would like to acknowledge the outstanding work of Ms. Charisse Lyle of the U.S. Army Combat Readiness/Safety Center for assistance with mishap and safety data and Dr. Amanda Kelley of the U.S. Army Aeromedical Research Laboratory for assistance with statistics. The authors would also like to acknowledge Ms. Diana Hemphill, Dr. Loraine St. Onge, and Ms. Catherine Machen for research assistance and technical editing.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official U.K. Ministry of Defence or U.S. Department of Defense position, policy, or decision, unless so designated by other official documentation. This work is original, has not been published elsewhere, and is not currently under consideration by another journal. There are no financial or other relationships that may be perceived as a conflict of interest. The manuscript has been reviewed and approved by all authors. All authors meet the specified journal criteria for authorship.

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