Fatigue-Related Aviation Mishaps

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INTRODUCTION: Fatigue is a critical safety issue to U.S. Air Force (USAF) flight and ground crew. Nearly 15 yr of mishap reports were analyzed to determine how fatigue affects USAF operations with the goal of improving fatigue risk management policies and tools.

METHODS: Summary data for 19,920 aviation mishap reports dating back to 2003 were collected from the Air Force Safety Automated System (AFSAS). Fatigue-related mishaps were identified based on designations provided within AFSAS. Other metrics examined were characteristics such as timing, cost, and aircraft metrics, among others. Contingency tables built from these metrics were used to assess fatigue-related trends across the aviation community.

RESULTS: While only 3.88% of all mishaps were identified as fatigue-related, they are associated with $2.1 billion of medical expenses and property damage, or 18% of the $11.7 billion total cost of all mishaps included in the study. Nearly a quarter of the fatigue-related mishaps fall into the most severe mishap category and more than half occurred between 0100 and 0700, local time. Fatigue-related mishaps tended to be more common for Remotely Piloted Aircraft (RPA) and ground operations.

DISCUSSION: Fatigue is very costly to the USAF despite the relatively low incidence rate of fatigue-related mishaps. This is because larger proportions of severe mishaps were found to be fatigue-related. RPA and ground maintenance operators might be especially susceptible to fatigue and potentially lack adequate fatigue mitigation support and training tailored to their unique operational environment, suggesting a need to improve upon fatigue mitigation tools and strategies.

KEYWORDS: fatigue, aviation, mishaps.

Gaines AR, Morris MB, Gunzelmann G. *Fatigue-related aviation mishaps*. Aerosp Med Hum Perform. 2020; 91(5):440–447.

Human fatigue is a critical safety issue within the aviation community. It is especially important to U.S. Air Force (USAF) air and ground crews, given the uniqueness of their operations. For example, mobility aircrew have flight duty period limits of 24 h (augmented crew) and missions often span numerous individual flight legs and multiple days, frequently crossing multiple time zones. They also operate in a dynamic environment where mission changes such as delays, rerouting, and extensions are common. In these environments fatigue cannot always be avoided. Therefore, there is a continual need to examine its effects on personnel and organizations and to improve upon fatigue risk management programs and regulations to mitigate the risks to safety and mission effectiveness. This study provides an updated examination of fatigue-related mishaps from the Air Force Safety Automated System (AFSAS). Specifically, we conduct a detailed examination of mishaps spanning 15 yr through a quantitative analysis regarding mishap characteristics such as timing, cost, and aircraft metrics among others.

Fatigue is a difficult concept to define given its multidimensional nature. Research suggests fatigue comprises several dimensions including general fatigue, mental fatigue, physical fatigue, sleepiness, and lack of motivation or activity.[1] Fatigue can result in acute, adverse outcomes in an operational environment. Fatigued individuals are less alert, have reduced ability to process information, and have slower reaction times than usual. These cognitive impairments contribute to operator errors and procedural violations which can ultimately result in costly damage to people and property (i.e., a mishap).[2] Although estimates vary, research indicates

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This manuscript was received for review in September 2019. It was accepted for publication in January 2020.

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DOI: https://doi.org/10.3357/AMHP.5515.2020

that fatigue is involved in at least 4–8% of aviation mishaps.[3] Few studies have examined incidents within the USAF, and have primarily relied on data from the Air Force Safety Center (AFSEC), formerly the USAF Safety Agency. In March 2007, AFSEC launched AFSAS, a mishap reporting and analysis system with a database that includes all reportable mishaps related to USAF aviation operations dating back to 2 October 1979.

These reportable mishaps are classified into four categories: Class A, B, C, or D. The classification is based on three possible factors: cost of damage, degree of injury, or occupational illness. Class A mishaps are the most severe, whereas Class D are the least severe. Current cost thresholds of Class D and Class C, B, and A mishaps were distributed by the Department of Defense (DoD) on 06 June 2011[5] and 01 October 2009,[15] respectively. Previously, all classes consisted of lower thresholds.[21] In addition to mishap class, aviation mishaps are classified with a subcategory regarding operation type: flight, flight-related, or ground operations (see U.S. Air Force[22] for mishap class and operation type definitions).

Research examining the association between these mishaps and fatigue has primarily focused on Class A mishaps. This research suggests that fatigue is present in about 13 to 25% of Class A mishaps and has been associated with multiple fatalities.[8,12,14] Studies have also examined other USAF incident reporting systems, such as Air Mobility Command's (AMC) voluntary, web-based reporting tool, Aviation Safety Action Program (ASAP). Morris, Wiedbusch, and Gunzelmann estimated that fatigue was associated with about 4% of the reported incidents.[10] Mission/duty length and mission planning were common contributors to fatigue, and aircraft operation violations were the most cited consequences of fatigue in these self-reported incidents. Not only does fatigue affect the performance of aircrew, but also that of personnel involved in ground operations servicing these missions. Few studies have examined fatigue incidents involving these personnel in the USAF. The Air Force Inspection Agency interviewed nonaircrew shift workers and found that 12% had experienced an adverse fatigue-related incident (as cited in Tvaryanas and Thompson[18]). Miller, Fisher, and Cardenas surveyed shift workers involved in ground operations across USAF major commands and organizations.[9] The researchers found that 13% of shift workers had experienced an adverse safety incident as a result of *shift-schedule induced fatigue*. These incidents included outcomes such as fatalities, injuries, property damage, and lost duty time.

Although these studies have reported relatively modest frequencies of fatigue-related mishaps, the studies suggest that fatigue can have substantial consequences such as fatalities[8] and can interact with other factors to make mishaps more likely to occur.[11] As a result, it is important to more closely examine the characteristics and consequences of fatigue-related mishaps. In the current study we examine several factors and their association with fatigue-related mishaps, such as mishap class severity, the hour of the day the mishaps occurred, the year the mishaps occurred, fatalities, aircraft type, operation type, and human factors associated with the mishaps. In addition, we examine several interactions among these factors to obtain a more nuanced understanding of these fatigue-related mishaps.

METHODS

Procedure

The study protocol was determined as Exempt Research by the Air Force Research Laboratory (AFRL) Institutional Review Board (IRB) under the common rule (32 CFR 219.104(d)(4)(ii)). We examined the AFSAS mishap repository which is a web-based database that includes a Data Extraction Tool (DET) that allows authorized users to examine mishap reports based on various characteristics. The DET then generates a table of mishap reports with the associated metrics requested from the user.

The simplest approach to ascertain which reports involved fatigue was to focus on two features present in AFSAS. The first feature is the DoD Human Factors Analysis and Classification System (HFACS) code structure based on work by Shappell and Wiegmann,[16] which mishap investigators use to identify myriad human factors which might have contributed to a mishap. We focused on mishaps involving nanocodes PC307 *Fatigu*e and PC215 *Mentally Exhausted (Burnout)*. Previous fatigue-related codes used in earlier iterations of the DoD HFACS[4,7] and USAF human factor analysis systems[23] such as *Circadian Desynchrony* were no longer present in the AFSAS nanocode system, but had been recategorized into the new nanocodes, and as a result, were not included in the current study.

The second feature was simply a column labeled "fatigue a possible factor." This designation was answered by the mishap investigator based on factors of the investigation.

All mishap reports were collected on 16 May 2018. The researchers requested all mishaps containing the *Fatigue/Mentally Exhausted* nanocodes and/or characterized as "fatigue a possible factor," with the following metrics from the DET request: Event Report Number; Event Date, Local; Event Class; Event Time, Local; Fatigue a Possible Factor; Total Fatalities; Total Event Cost with Injuries; MDS Category (Aircraft Type); Subcategory Tier 1 (Operation Type); DoD HFACS Nano Code Tier 2.

Statistical Analysis

For statistical analysis, we developed contingency tables within Microsoft Excel to calculate frequencies and proportions based on metric information to assess fatigue-related trends across the aviation community in the USAF in an attempt to determine where fatigue has the greatest operational impacts. To examine significant differences in proportions or comparing count distributions we conducted a test of equal proportions or a Chi-sqaured test of independence in *R*[13], respectively. To test for directional linear trends in proportions, we conducted a Cochran-Armitage test with the *DescTools* package,[17] which provides a Z score.

RESULTS

Mishap Class

Since 2003, 19,920 Class D or higher mishaps have occurred, costing the USAF a total of \$11.7 billion. While only 3.88% (773 of 19,920) of these mishaps were fatigue-related, they are responsible for \$2.1 billion worth of damage and medical expenses, 18% of the total cost of the mishaps, and resulted in 32 fatalities. This is largely due to the disproportionate number of fatigue-related mishaps classified as Class A, suggested by a significant difference among the proportions ($\chi^2(3) = 917.93$, $P < 0.001$) and a significant decreasing linear trend in the proportions (from Class A to D) ($Z = -27.94$, $P < 0.001$). By class, the following proportions of mishaps were found to be fatigue-related: 24.05% (133 of 553) of Class A mishaps, 9.93% (118 of 1188) of Class B mishaps, 4.42% (450 of 10,187) of Class C mishaps, and 0.90% (72 of 7992) of Class D mishaps. This relationship between fatigue-related mishap occurrence and mishap class is consistent across all aircraft types and for both flight and ground operations.

Timing

Examining the local time associated with when the mishaps occurred (19,477 mishaps were categorized with a time), fatigue-related mishaps occurred most frequently between 0100 and 0700. This 6 h time window encompasses 50.26% (388 of 772) of fatigue related mishaps, but only 9.19% (1790 of 19,477) of all mishaps. Additionally, the proportion of annual FY fatigue-related mishaps during the 0100 to 0700 period has increased in recent years, ($Z = 2.63$, $P < 0.01$) (see **Table I**; readers should note that 2003 and 2018 are partial fiscal years and were not included in the analysis).

By breaking down the fatigue-related mishaps by class, we found that the proportion of fatigue-related mishaps within the 0100 to 0700 time period compared to fatigue-related mishaps during all hours increases as mishap severity decreases ($Z = 4.73$, $P < 0.001$). This time period contains 23.48% (31 of 132) of Class A, 38.98% (46 of 118) of Class B, 58.44% (263 of 450) of Class C, and 66.67% (48 of 72) of Class D fatigue-related mishaps. The proportion of fatigue-related mishaps to all mishaps during only the 0100 to 0700 time frame increases with mishap severity ($Z = -11.87$, $P < 0.001$). Between 0100 and 0700, 59.62% (31 of 52) of Class A, 48.94% (46 of 94) of Class B, 31.12% (263 of 845) of Class C, and 6.01% (48 of 799) of Class D were fatigue-related. The increased incidence of fatigue-related mishaps during 0100 to 0700 for lower class mishaps appears to be largely driven by ground operations, suggested by a Chi-squared test of independence, $\chi^2(3) = 175.21$, $P < 0.001$. An examination of the Pearson residuals from the analysis suggested that ground operations had moderate positive associations with Class C and D mishaps, compared to flight and flight-related operations that had negative associations with these classes. The data suggested aircraft type was not associated with fatigue-related mishap differences during this time period.

The annual fatigue-related mishap count over all hours has gradually increased since FY2014. The total number of mishaps (fatigue and non-fatigue-related) increased substantially from FY2008 to FY2009 (from 780 to 1430) and has remained quite stable ($M = 1725.8$) over the last 5 full years (FY2013 – FY2017) (see Table I).

Examining mishaps by fiscal year and class, it is clear that the large increase in the total number of mishaps after FY2008 is largely attributable to an increase in Class D mishaps (see **Fig. 1**). Additionally, there was an increase in fatigue-related Class D mishaps in FY2017 and the partial FY2018 (see **Fig. 2**). When Class D mishaps are excluded, the total mishap counts are fairly similar ($M = 769$, Mdn = 747) across the last 14 full years of data. The proportions of mishaps that are fatigue-related are similar after FY2008 ($M = 7.85\%$, Mdn = 7.76%) (see **Fig. 3**).

Table I. Fatigue-Related Mishaps 0100 – 0700 Time Window and FY Proportion (2003 – 2018).

YEAR	FATIGUE MISHAPS (0100-0700)	FATIGUE MISHAPS (ALL HOURS)	ALL MISHAPS (0100-0700)	ALL MISHAPS (ALL HOURS)	PROP FATIGUE MISHAPS (0100-0700)	PROP FATIGUE TO TOTAL MISHAPS (0100-0700)
2003	2	4	38	543	0.50	0.05
2004	1	7	53	820	0.14	0.02
2005	3	11	75	951	0.27	0.04
2006	3	10	31	747	0.30	0.10
2007	18	59	43	753	0.31	0.42
2008	8	27	35	780	0.30	0.23
2009	41	91	138	1430	0.45	0.30
2010	35	63	157	1369	0.56	0.22
2011	21	53	137	1434	0.40	0.15
2012	25	48	130	1528	0.52	0.19
2013	31	57	160	1694	0.54	0.19
2014	29	56	173	1719	0.52	0.17
2015	31	64	173	1774	0.48	0.18
2016	43	75	177	1719	0.57	0.24
2017	52	89	176	1723	0.58	0.30
2018	45	59	94	936	0.76	0.48
Total	388	773	1790	19,920	0.50	0.22

Note: FY2003 and FY2018 are not a full year of data. Prop = Proportion.

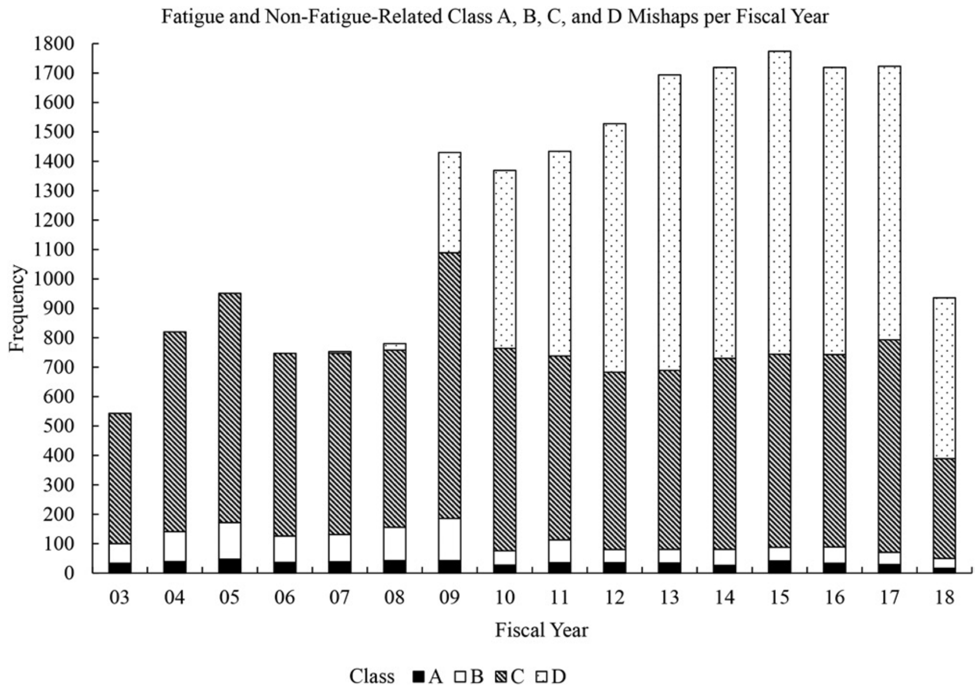

Fig. 1. Fatigue and non-fatigue-related Class A, B, C, and D mishaps per fiscal year. Note: FY2003 and FY2018 are not a full year.

Aircraft Type

A majority of aircraft were associated with fatigue-related mishap proportions (fatigue-related mishaps to total mishaps) from 3 to 6%. However, the Remotely Piloted Aircraft (RPA) fatigue-related mishap proportion was 13.85%, well above estimates of the other aircraft types (see **Table II**). In terms of mishap cost, fatigue-related mishaps are more expensive on average compared to non-fatigue-related mishaps for every type of aircraft except bombers. However, examining the median cost of mishaps, a more representative reflection of the typical mishap, the costs for fatigue-related mishaps tend to be higher compared to non-fatigue-related mishaps for all aircraft except trainers (see Table II). RPA mishaps tend to be especially costly compared to other aircraft. Bombers and tankers are the only manned

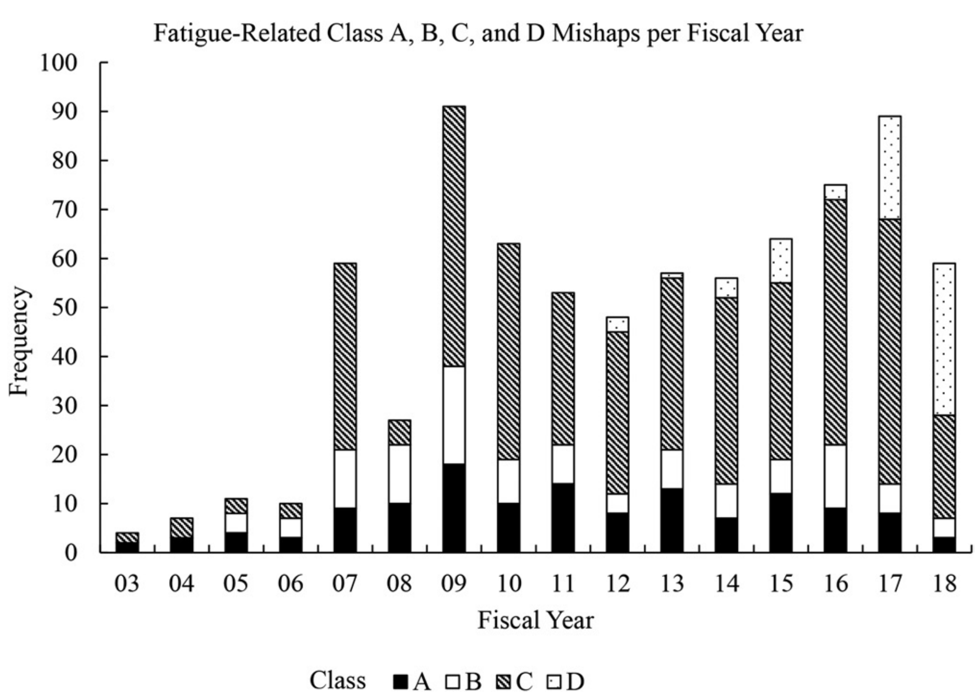

Fig. 2. Fatigue-related class A, B, C, and D mishaps per fiscal year. Note: FY2003 and FY2018 are not a full year.

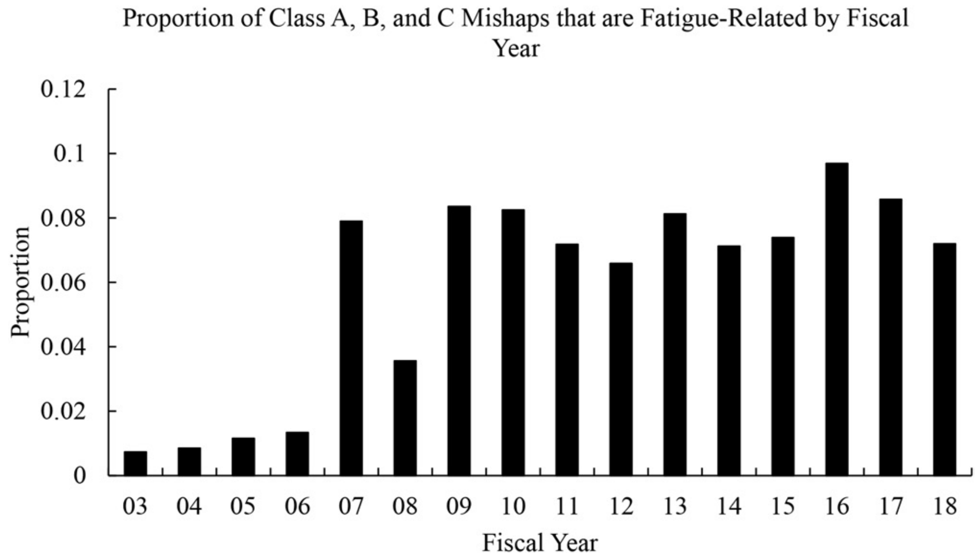

Fig. 3. Proportion of Class A, B, and C mishaps that are fatigue-related by fiscal year. Note: FY2003 and FY2018 are not a full year.

aircraft types that have no fatalities associated with fatigue-related mishaps during the period reviewed (see **Table III**).

Operation Type

All fatigue-related mishaps were designated as flight, flight-related, or ground operations except for one mishap, which did not have a designation. To simplify analyses, we combined the flight and flight-related mishaps. The overall incidence rate for fatigue-related mishaps was higher for ground mishaps at 4.43% (475 of 10,716) compared to the flight mishap rate of 3.24% (298 of 9203). However, fatigue-related flight mishaps tended to be more severe, with Class A, B, C, and D counts being 126, 88, 74, and 10, respectively; whereas, for ground operations they were 7, 30, 376, and 62, respectively. A Chi-squared test of independence suggested dependence among the operation type and mishap classes ($\chi^2(3) = 353.20, P < 0.001$). An examination of the Pearson residuals from the analysis suggested flight and flight-related operations had a strong positive association with Class A mishaps and a strong negative association with Class C mishaps, whereas ground operations had a strong negative association with Class A mishaps and a moderate positive correlation with Class C mishaps. Additionally, of the 32 fatigue-related mishaps that resulted in fatalities, only one was categorized as ground operations.

Human Factors Interactions and Consequences

In general, human factors were identified in a greater proportion of the fatigue-related mishaps than in the other mishaps. The most common human factors that were identified in fatigue-related mishaps are PC101 *Not Paying Attention*, AE201 *Inadequate Real-Time Risk Assessment*, AE103 *Procedure Not Followed Correctly*, AE206 *Wrong Choice of Action During an Operation*, and PC102 *Fixation* (for a more comprehensive list of common factors see **Table IV**).

Different aircraft types generally had similar human factors associated with fatigue-related mishaps. However, RPA had particularly high percentages of OP003 *Provided Inadequate Procedural Guidance* (40.23% compared to 7.61–17.86%), OP007 *Purchasing or Providing Poorly Designed or Unsuitable Equipment* (33.33% compared to 0.00–6.12%), and PE202 *Instrumentation and Warning System Issues* (27.59% compared to 0.00–3.36%) compared to the other aircraft.

Table II. Frequency, Mean, and Median Costs of Mishaps Across Aircraft Type.

	NON-FATIGUE-RELATED MISHAPS			FATIGUE-RELATED MISHAPS			
AIRCRAFT TYPE	*F*	Mean	Median	*F*	Mean	Median	Total *F*
Bomber	1423	$1895,158	$38,371	66	$530,154	$106,806	1489
Fighter/Attack	6098	$538,450	$28,703	238	$3237,062	$49,662	6336
Helicopter	462	$704,675	$61,212	28	$3549,506	$174,270	490
ISR/BM/C3	910	$498,012	$30,036	28	$11,873,079	$35,500	938
RPA	541	$1393,570	$100,000	87	$3772,464	$3807,680	628
Special Ops	1065	$478,492	$36,310	49	$1827,385	$193,428	1114
Tanker	2605	$146,296	$25,477	92	$456,714	$44,807	2697
Trainer	1403	$171,623	$36,315	10	$1744,447	$6650	1413
Transport	4579	$210,696	$14,266	171	$2409,028	$27,851	4750

Note: ISR/BM/C3 = Intelligence, Surveillance, and Reconnaissance/Ballistic Missile/Command, Control, and Communication; *F* = Frequency. Data for aircraft types listed as "No Data" or "Other" are not included.

Table III. Total Fatalities and Class A Mishaps by Aircraft Type and Fatigue Indication.

	NON-FATIGUE		FATIGUE				TOTAL	
AIRCRAFT	FATAL	MISHAP	FATAL	PROP FATAL	MISHAP	PROP MISHAP	FATAL	MISHAP
Bomber	13	27	0	0	3	0.10	13	30
Fighter/Attack	27	135	11	0.29	33	0.20	38	168
Helicopter	25	18	1	0.04	9	0.33	26	27
ISR/BM/C3	11	15	1	0.08	3	0.17	12	18
No Data	11	8	4	0.27	3	0.27	15	11
Other	1	1	0	0	0	0	1	1
RPA	0	123	0	0	59	0.32	0	182
Special Ops	15	8	7	0.32	6	0.43	22	14
Tanker	9	19	0	0	3	0.14	9	22
Trainer	6	19	4	0.40	3	0.14	10	22
Transport	25	52	4	0.14	12	0.19	29	64

Note: ISR/BM/C3 = Intelligence, Surveillance, and Reconnaissance/Ballistic Missile/Command, Control, and Communication; Ops = Operations; Fatal = Fatalities; Mishap = Mishaps; Prop = Proportion.

DISCUSSION

We found that roughly 4% of USAF aviation mishaps in our dataset involved fatigue, which is consistent with estimates of fatigue-related incidents across other aviation communities.[3,10] Additionally, our estimates for fatigue-related Class A mishaps are similar to those of studies that found larger proportions.[8,12,14] However, it should be noted that the researchers in these studies might have used a different definition for fatigue-related mishaps than the one used in the current study, resulting in some uncertainty when comparing these outcomes. Given the similarity of our findings to past research, fatigue mitigation processes and tools implemented in recent years might not be as successful in combating fatigue as one would expect. Alternatively, similar findings to past data despite advances in fatigue mitigation technology may reflect an increase in operations tempo over the years due to a need for continuous global operations. Supporting this proposition, we found that the proportion of fatigue-related mishaps has increased in recent years. We also found that as mishap class increases, fatigue is more frequently cited as a possible factor. This could be due to fatigue's interaction with other factors resulting in more serious incidents. For example, spatial disorientation is more likely to occur when fatigue is present, and is one of the leading causes of pilot fatality.[11] Another possibility is that costlier mishaps result in more rigorous investigations (Hatter, ER. Personal communication; 2018) and thus might identify human factors such as fatigue more often. The investigation procedures and techniques outlined in AFM 91-223 *Aviation Safety Investigations and Reports* are focused on Class A and B mishaps, but states that applicable processes and techniques should be applied to the other mishap classes.[20] As a result, investigations might be under-reporting fatigue in the less extreme mishap classes.

In terms of trends in total mishaps and fatigue-related mishaps, there appeared to be a large increase in total mishaps in FY2009 and a large increase in fatigue-related mishaps in FY2007. A closer examination of this trend suggested that a general increase in Class C and D mishaps, as well as an increase in Class C mishaps with ground operations were drivers of this trend. The increases in lower Class mishaps might be due to several factors, such as the introduction of the AFSAS system in 2007, which might have influenced the reporting of mishap investigations, and changes to cost thresholds for mishap classes in 2009, among others. Given these possibilities, these trends should be interpreted with caution.

In terms of timing of fatigue-related mishaps, we found that they were most likely to occur during 0100 to 0700. The relatively low number of mishaps overall during this time frame suggests that there are fewer operations at night than at other times of day, although the data to confirm this are not readily available. However, the high incidence rate of fatigue-related mishaps suggests that additional countermeasures are required to mitigate the effects of fatigue at night and during the early morning hours. We found that the proportion of fatigue-related mishaps for each class during this time period compared to other time periods decreased with increased class severity. This trend might be driven by investigative differences among the mishap classes. Since Class A and B mishaps require human factors investigations, investigations for mishaps outside of the 0100 to 0700 time period might be more likely to find fatigue as an associated factor. Human factors investigations are not required for Class C and D mishaps, so investigators might assume that early morning mishaps involve fatigue or that midday mishaps do not involve fatigue. Additionally, we found that the proportion of fatigue-related mishaps to all mishaps for each class during this time period increased with increased class severity. This trend is consistent with the overall fatigue to non-fatigue-related mishap proportions (regardless of time period) for each class, where more severe mishap classes tended to have higher proportions of fatigue-related mishaps. Again, due to investigative differences for each class these patterns should be interpreted with caution.

Although different aircraft types tended to have modest rates of fatigue-related mishaps, fatigue was more likely to be a factor in mishaps involving RPAs. RPAs are often piloted from inside ground control stations, and crews often work shift schedules to meet continuous operation requirements. Studies have suggested that both RPA aircrew and maintenance experience more fatigue compared to manned aircraft aircrew and

Table IV. Percentage of Fatigue-Related and Non-Fatigue-Related Mishaps with Human Factors.

HFACS CODES	FATIGUE	NON-FATIGUE
PC101 Not Paying Attention	15.96	8.27
AE201 Inadequate Real-Time Risk Assessment	14.60	4.90
AE103 Procedure Not Followed Correctly	14.32	2.88
OP003 Provided Inadequate Procedural Guidance or Publications	13.37	2.80
AE206 Wrong Choice of Action During an Operation	13.10	3.68
PC102 Fixation	12.28	2.84
PC208 Complacency	11.73	3.28
PC504 Misperception of Changing Environment	9.82	2.38
PP108 Failed to Effectively Communicate	8.46	1.41
AE102 Checklist Not Followed Correctly	8.32	1.74
SI003 Failed to Provide Proper Training	7.23	0.93
AE107 Rushed or Delayed a Necessary Action	6.96	2.33
OP007 Purchasing or Providing Poorly Designed or Unsuitable Equipment	6.68	1.38
PE101 Environmental Conditions Affecting Vision	6.68	1.03
AE105 Breakdown in Visual Scan	6.55	1.18
PC106 Distraction	6.41	1.13
AE104 Over-Controlled/Under-Controlled Aircraft/Vehicle	6.00	1.42
OP004 Organizational (formal) Training is Inadequate or Unavailable	5.46	0.71
SI001 Supervisory/Command Oversight Inadequate	5.32	1.07
PC206 Overconfidence	4.91	1.14
PE202 Instrumentation and Warning System Issues	4.64	0.46
PC103 Task Over-Saturation/Under-Saturation	4.09	0.48
OP001 Pace of Ops-Tempo/Workload	4.09	0.43
AE101 Unintended Operation of Equipment	4.09	0.68
PC110 Inaccurate Expectation	3.96	0.63
AE205 Ignored a Caution/Warning	3.96	0.81
PC104 Confusion	3.82	0.35
PC109 Technical or Procedural Knowledge Not Retained after Training	3.82	0.57
AE202 Failure to Prioritize Tasks Adequately	3.82	0.86
PP106 Critical Information Not Communicated	3.68	0.67
SI008 Selected Individual with Lack of Proficiency	3.55	0.57
PC105 Negative Habit Transfer	3.27	0.52
PC209 Motivation	3.27	0.60
OP006 Inadequate Program Management	3.14	0.35

Note: We report nanocodes ≥ 3.00% for fatigue-related mishaps. PC307 Fatigue and PC215 Mentally Exhausted (Burnout) are not included as they are markers of fatigue-related mishaps.

maintenance personnel.[18] In addition, fatigue-related mishaps associated with RPAs tended to have much higher rates of other human factors issues compared to other aircraft types. These human factors also dealt with lack of procedural guidance and publications, the purchase or use of poorly designed or unsuitable equipment, and issues with instrumentation and warning systems, human factors that were not cited as frequently in mishaps involving other aircraft types. This is most likely due to how young and unique this aircraft type is relative to other types and crews. Consequently, this population might require special attention in terms of fatigue-related incidents and modified fatigue risk management strategies.

Results suggested that flight operations were associated with more severe mishaps compared to ground operations. This reinforces the continuous need to focus on mitigating aircrew fatigue. On the other hand, ground operations constituted a larger proportion of fatigue-related mishaps compared to flight operations. Although some ground operation mishaps involve aircrew, this suggests a need to focus on fatigue risk management for ground crew as well. Currently, the USAF implements Maintenance Resource Management (MRM) training that focuses on reducing errors through human factors in maintenance activities.[6] This training is a variant of the Air National Guard MRM.[19] Fatigue risk management might require more attention within this community, perhaps in the form of further training or other supplemental programs.

Lastly, our findings suggested that fatigue-related mishaps are associated with a greater proportion of human factors identified in investigations compared to non-fatigue-related mishaps. This was expected given that fatigue commonly results in cognitive impairments such as decreased alertness, delayed reaction time, and diminished information processing[2] and interacts with other environmental issues making mishaps more likely to occur.[11] However, it should be noted that since we used fatigue-related HFACS nanocodes to identify fatigue mishaps, these might over-represent mishaps in which the investigators paid more attention to human factors. In other words, if the investigators identified *Fatigue* or *Mentally Exhausted* as nanocodes associated with the mishap, they might be more likely to identify other human factor nanocodes since they are investigating human factors.

The current study provided an updated, nuanced examination of fatigue-related mishaps in the USAF. We specifically investigated several factors such as mishap class severity, timing, aircraft type, operation type, and human factors and their association with fatigue-related mishaps. Our findings suggest that fatigue continues to be a critical safety issue to USAF air and ground operations which has costly consequences. Specific crew types, such as RPA pilots and ground maintenance crews might be especially susceptible to fatigue. Meanwhile, they might also lack adequate fatigue mitigation support and training tailored to their unique operational environment, resulting in increased frequency of fatigue-related mishaps. Fatigue is also impactful among other crew types. Over the last 15 yr, fatigue-related mishaps have resulted in 32 fatalities and have cost the USAF over $2 billion. Therefore, there is a continual need to enhance fatigue risk management programs and training for both aircrew and maintenance crew across all types of aircraft.

ACKNOWLEDGMENTS

The views presented in this paper are those of the authors, and do not represent the official position of the United States Air Force or Department of Defense. We would like to thank the U.S. Air Force Safety Center for providing guidance in the access of the Air Force Safety Automated System repository and for their assistance in manuscript editing. Dr. Megan Morris completed a majority of this work as a contractor with Ball Aerospace and 1st Lt Alex Gaines completed a majority of this work while at the Air Force Research Laboratory. This research was funded in part with support from the 711th Human Performance Wing. Distribution A: Approved for public release; distribution unlimited. 88ABW Cleared 04/24/2019; 88ABW-2019-1412.

Financial Disclosure Statement: The authors have no conflicts to declare.

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