

Compound Fatigue Risk in Medium-Haul Pilots

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ABSTRACT

INTRODUCTION: Fatigue from multiple sources (e.g., circadian, workload, stress, etc.) can create a compound safety risk. Pilots operating medium haul (M-H) routes may be susceptible to compound fatigue, but sources of fatigue in M-H operations have not been robustly quantified.

METHODS: In an anonymous survey, airline pilots working M-H rosters were asked to rank on a scale of 0 to 10 the level of fatigue they experience from 40 separate factors across four domains: 1) circadian; 2) environmental; 3) operational; and 4) psychosocial, with higher scores indicating more fatigue. Pilots also reported habitual sleep duration.

RESULTS: Two hundred twenty-three pilots (90 Captains; 133 First Officers) completed the survey. Pilots rated circadian factors as most fatiguing (mean (SD); 6 (1)), followed by factors in the psychosocial and environmental domains (both 5 (1)), and finally, the operational domain (4 (2)). Pilots reported sleeping seven hours on average; sleep was not significantly related to fatigue ratings.

DISCUSSION: Operational fatigue factors related to higher work volume (e.g., working longer hours, shorter breaks, etc.) were rated as more fatiguing. Schedule features that impinge on the window of circadian low (e.g., early starts, late ends) were fatiguing even in M-H pilots with daytime schedules that allow for sufficient sleep duration.

KEYWORDS: human factors, workload, fatigue, safety risk, medium-haul, commercial aviation

INTRODUCTION

Pilot fatigue constitutes a well-acknowledged risk to aviation safety. Regulatory organizations like the European Union Aviation Safety Agency (EASA) have imposed rules to address ways in which fatigue can be limited during operations.¹ This includes the use of a fatigue risk management system (FRMS).² An FRMS is a data-driven management system used to monitor and mitigate the effects of fatigue, and the safety risks associated with fatigue-related errors in operations. Identifying the factors that contribute to fatigue under specific circumstances is central to the idea that FRMS can provide flexible mitigation strategies rather than being a “one-size-fits-all” solution like flight and duty time limitations.³ One issue limiting the ability to identify fatigue factors is the ability to define fatigue itself. The International Civil Aviation Organization identifies fatigue as “a physiological state of reduced mental or physical performance capability” resulting from sleep loss, circadian phase, or workload.² The word “fatigue” may have different connotations depending on the language or regional culture. It is therefore good practice to assess the subjective experience and possible causes of fatigue using participants’ native language as much as possible.^{4,5}

The causes of fatigue in aviation vary by the type of operation. Flight operations are commonly categorized using colloquial industry terms that describe the distance travelled during the flight duty period relative to the length of other operations. While these are not regulatory definitions, EASA considers short-haul (S-H) to refer to flights less than 500 kilometers (km) long, medium-haul (M-H) to refer to flights between 500 and 5,000 km long, and long-haul (L-H) flights to refer to flights that are 5,000 km or longer.⁶ Long duty days, flying during the window of circadian low, circadian disruption due to time zone crossings, and sleep disruption are common fatigue factors for L-H flights.² Fatigue in S-H operations commonly stems from

restricted sleep opportunities, early starts, or late finishes, but also from workload factors like the number of flight segments per day, or number of consecutive duty days.^{2,7} It has been shown that flight duty periods that include multiple flight segments, and thus, multiple takeoffs and landings per duty period, are more fatiguing to the pilot than a single takeoff and landing even when the duration of the flight duty period is similar.⁸ Flights with a shorter duration may result in greater fatigue across the pilot's entire flight duty periods because they allow for more flight segments within the duty time limitation.⁹

To paraphrase, the major cause of fatigue in S-H operations is considered to be high workload while L-H operations are considered fatiguing primarily due to sleep and circadian disruption (even though workload, sleep and circadian fatigue are acknowledged as affecting operations of any length).⁷⁻⁹ Extrapolating from these findings, we may postulate that the least fatiguing type of operation would consist of daytime flying that does not cross multiple time zones, only requires one or two takeoffs and landings per duty period and allows the pilot to return to base for sleep periods. This is the type of flying seen in European M-H operations. S-H and M-H flight segments are often combined into one category when analyzing fatigue factors,⁷ but the two types of operations are distinctly different from each other and different between the European and North American markets.^{6,10} The typical pattern of M-H operations can vary depending on the region of operation or routes provided by a specific airline. For example, M-H operations in North America may routinely include east/west travel that crosses multiple time zones whereas M-H operations in European carriers are predominantly north/south routes that do not cross time zones.

Prospective fatigue evaluation tools like biomathematical models of fatigue (BMMF) historically have predicted fatigue risk within one domain—traditionally physiological alertness.

Most BMMFs used for schedule evaluation in aviation predict fatigue as a function of the three-process model of alertness, with the three processes being sleep duration, time of day, and sleep inertia.¹¹ One of the strengths of BMMFs is that they predict dynamic changes to alertness based on scientific knowledge of well-established biological rhythms.¹² Some BMMFs have begun to incorporate workload factors into their alertness predictions,^{13,14} but there is no standardized method for modeling fatigue outside of the biological domain. Previous attempts to model workload in the aviation context did not assess the fatigue associated with explicit work tasks, but rather focused on fatigue at specific time points during the flight.^{14,15} Finally, previous reports of pilot fatigue during operations have concentrated on S-H and/or L-H.^{14,15} Modeling fatigue related to M-H operations remains under characterized.

Pilots operating M-H flights likely do not experience fatigue in the same way that S-H or L-H pilots do, but this does not mean that the pilots experience no fatigue at all. Findings that combine S-H and M-H operations may be conflating the fatigue associated with certain factors between the two. Implementing mitigations that target fatigue factors identified from a data collection may be confounded by the fact that fatigue factors from different domains are not mutually exclusive. As an example, a pilot may experience fatigue in the circadian domain when schedules include work that overlaps with periods of low circadian arousal, such as early mornings, late evenings, or overnight flights. Pilots may experience operational fatigue when schedules involve long duty hours, multiple flight legs, or short sit times. Environmental fatigue may arise from foul weather conditions or the ambient environment within the cockpit, including noise or temperature. Finally, psychosocial fatigue can occur because of stress, frustration, or human relations, such as working with an uncooperative co-pilot. Aviation can be a stressful work environment, particularly in the midst of global changes to daily operations and travel.¹⁶ A

successful FRMS should therefore consider ways to support aviation worker wellbeing at the organizational level.¹⁷ The COVID-19 pandemic impacted flight operations and could have constituted a significant source of psychological fatigue independently from infection with the virus, for example, stress related to wearing an uncomfortable face mask for hours on end in the cockpit, known in the literature as “mask fatigue.”¹⁸

Here, we introduce the concept of “compound fatigue risk”, or the idea that incremental amounts of fatigue from different sources, including extended wakefulness, workload, and stress, may combine to create a greater overall level of risk. The impact of compound fatigue risk on operational safety has not been robustly addressed. The current project describes the steps taken to identify which attributes of the work environment M-H pilots found most fatiguing from across four discrete domains: 1) circadian factors; 2) operational or scheduling factors; 3) environmental factors and; 4) psychosocial, COVID mandate-related, or interpersonal factors. To our knowledge, this is the first survey asking pilots to report sources of fatigue associated specifically with M-H operations across multiple domains.

METHODS

Subjects

A European-based commercial airline agreed to share previously-collected survey data with the study team for secondary analysis under the condition of anonymity. Subjects provided informed consent prior to their participation in the original study. Secondary use of de-identified data for research purposes was deemed non-human subjects research by Salus IRB on October 11, 2024 (Study ID: 23446) and these analyses were conducted in accordance with the Declaration of

Helsinki. Salus IRB is an independent, appropriately constituted and fully accredited institutional review board based in Austin, Texas, USA.

Pilots operating M-H routes for the airline during the years 2020 and 2021 were recruited by the airline's Safety Department through email and in-person convenience sampling for the interview and survey portions of the study. All pilots were considered eligible for inclusion regardless of gender, ethnicity, age (over 18), sleep habits, or health status.

Procedure

Study procedures took place in four parts as demonstrated in **Fig. 1**. All interviews and surveys were completed in the pilots' native language and translated to English after completion of the study. As a first step, a preliminary sample of 8 pilots (7 men, mean age = 41) were recruited offline for unstructured interviews using convenience sampling. Interviews were all conducted by the same interviewer. Pilots were asked to describe fatigue during M-H operations in their own words. The aim of the interviews was to identify common sources of fatigue within the M-H fleet to ensure that the content of the final fatigue survey would be relevant to the target population. Each interview transcript was analyzed independently by the interviewer. Key terms that summarized a fatigue factor were extracted from the interview transcripts using qualitative research methodology.⁷ Duplicate, idiosyncratic, or poorly worded items were removed.

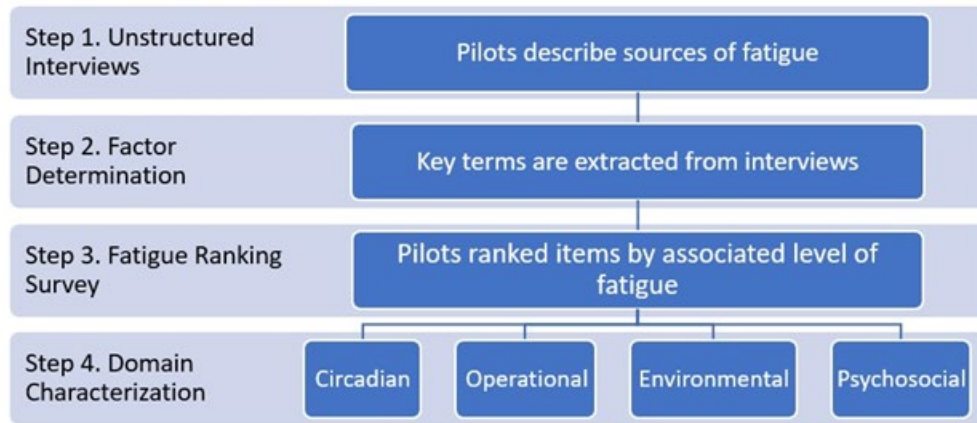


Fig. 1. Procedural flowchart describing the steps taken to characterize sources of pilot fatigue across domains.

In total, 40 items were identified as common fatigue factors as identified by the interview process. The 40 items were compiled into an anonymous online survey which asked pilots to rate each factor from Not at All Fatiguing (0) to Extremely Fatiguing (10) using an adapted version of the Rating of Fatigue Scale.⁵ The survey was hosted on the airline's internal survey platform; a link was sent to M-H pilots' work emails. Neither the pilot's email address nor any other identifying information was collected as part of the online survey. Pilots were asked to rate the fatigue that they felt on average while performing each of the 40 items independently. Survey items were displayed randomly to pilots to avoid order effects. Pilots were also asked to provide demographic information about their age, years of experience and rank, and sleep behavior. Survey items were categorized based on fatigue domain (Circadian, Operational, Environmental, Psychosocial). An English translation of survey items is listed by domain in **Table I** below.

Table I. English Translation of Survey Items by Fatigue Domain.

DOMAIN	SURVEY ITEMS
Demographics	• Age

	• Habitual sleep duration • Rank (captain or first officer) • Flight hours
Circadian	1. Arrival after 10 PM 2. Briefing before 6 AM 3. Briefing before 7 AM 4. Early wake up 5. Late-early transition
Operational	6. Air Traffic Control (ATC) 7. Change of cabin crew 8. Change of plane 9. Coordination with ground 10. Commuting to work 11. Consecutive days on (2 ON) 12. Consecutive days on (3 ON) 13. Consecutive days on (4 ON) 14. Consecutive days on (5 ON) 15. Consecutive days on (6 ON) 16. Number of legs per day (1 Leg) 17. Number of legs per day (2 Legs) 18. Number of legs per day (3 Legs) 19. Number of legs per day (4 Legs) 20. Flight duty time > 10 hours 21. Short rest <12 hours 45 minutes 22. Sit time >60 minutes 23. Sit time >120 minutes 24. Transfer to hotel > 60 minutes 25. Technical tolerances 26. Positioning flight
Environmental	27. Noise 28. Terrain Category B 29. Terrain Category C 30. Cold weather operations (CWO) 31. Low visibility operations (LVO)

	32. Thunderstorm
	33. Wind
Psychosocial	34. Group compatibility
	35. Mask wearing
	36. Little recent experience
	37. Particular context
	38. Task interruption
	39. Time pressure
	40. Work-life balance

Statistical Analysis

All analyses were done in Excel 2013 (Microsoft Corporation, Redmond, Washington, USA) and STATA MP 15 (StataCorp, College Station, Texas, USA). The Excel 13 Rank function was used to calculate weighted mean rank order for all 40 fatigue factors independently from domain.

Fatigue rank was furthermore investigated within domains: 1) Circadian; 2) Environmental; 3) Operational; and 4) Psychosocial. Linear regression was used to examine the influence of habitual sleep duration on pilots' overall rating of fatigue, as well as mean fatigue ratings within each domain. Statistical significance was assumed at $p \leq 0.05$.

RESULTS

Pilot demographics are summarized in **Table II**. Two hundred twenty-three M-H pilots (90 Captains; 133 First Officers) completed the online survey. Pilots were 43 (9) years old, with over 8000 hours of flight time over the course of their professional careers. For reference, EASA limits commercial pilots' total flight time to 1000 hours/year.¹ Pilots indicated that they normally slept 7 hours, which is in line with the National Sleep Foundation's recommendations that adults

receive 7-9 hours of sleep per night.¹⁹ Habitual sleep duration did not predict higher fatigue ratings overall or fatigue within domains (all $p>0.05$).

Table II. Pilot Demographics.

DEMOGRAPHIC VARIABLE	MEAN $\pm$ STANDARD DEVIATION
Age	43 $\pm$ 9 yr
Habitual sleep duration	7 $\pm$ 1 h
Rank (captain or first officer)	Captain: N=90; First Officer: N=133
Flight hours	8561 $\pm$ 4988 h

Fatigue rating for each item by domain are depicted in **Fig. 2**. Items are ranked top to bottom from most fatiguing to least fatiguing within domains. Domains are organized from most fatiguing (top) to least fatiguing (bottom). The mean fatigue rating across all five items in the Circadian domain was 5.7 ± 1.7 out of a maximum rating of 10. The mean (SD) fatigue rating across all seven items in the Psychosocial domain was 4.8 (1.5) while the mean rating across all seven items in Environmental domain was 4.7 (1.7) and the average rating across all 21 items in the Operational domain was 4.4 (1.2). Pilots rated “Noise” from the Environmental domain as more fatiguing than any other item, with a mean rating of 7.4 (2.1) followed by: “Briefing before 6AM” with a mean rating of 7.3 (2.2) and “Late-early transition” with a mean rating of 6.9 (2.4) in the Circadian domain. Working six consecutive days, or “6 ON” with a mean rating of 6.9 (2.5) and flight duty times longer than ten hours with a mean rating of 6.8 (2.1) were rated as most fatiguing in the Operational domain. The most fatiguing item in the Psychosocial domain was wearing a mask to prevent the spread of COVID-19, or “Mask” with a rating of 6.0 (2.8).

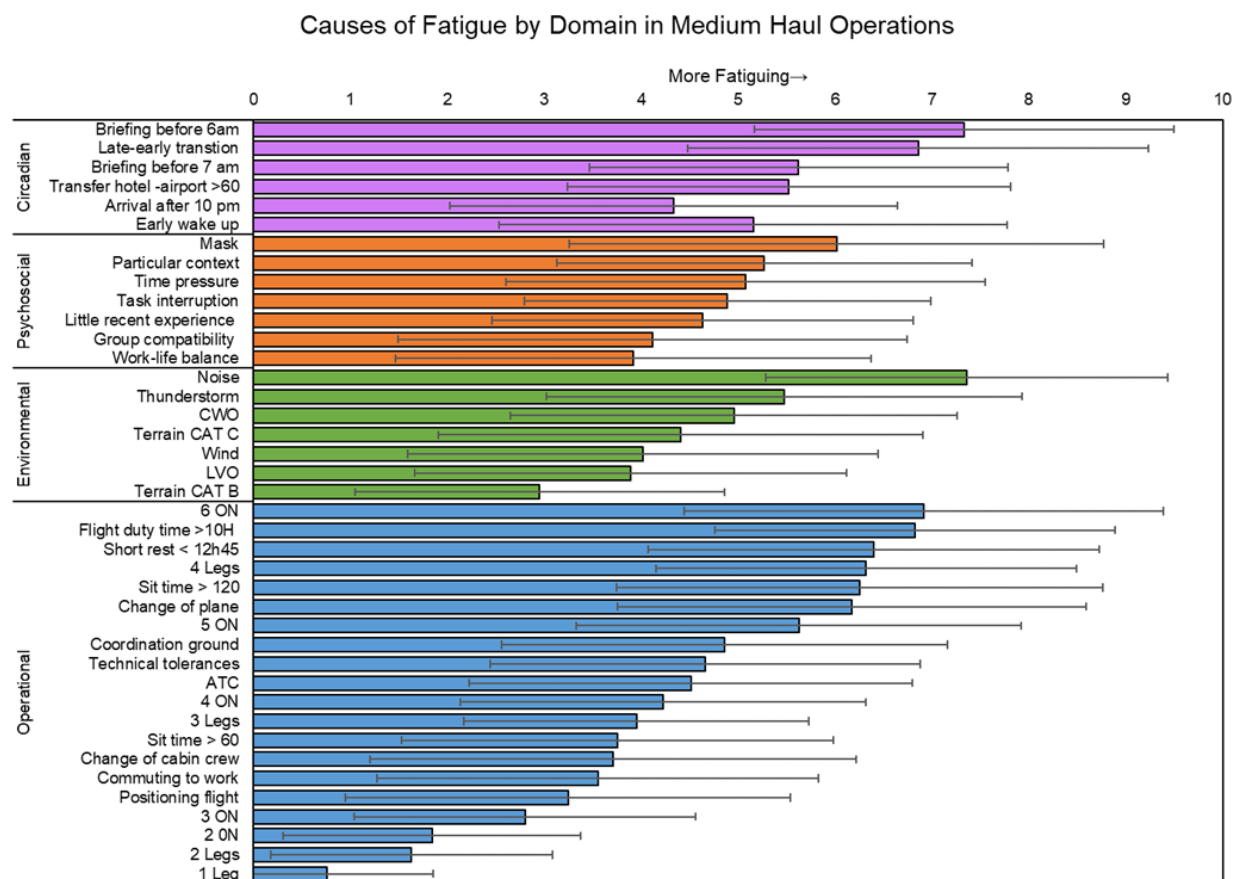


Fig. 2. Causes of fatigue by domain in medium-haul operations. Mean fatigue ratings by item across Circadian, Psychosocial, Environmental and Operational fatigue domains. Domains are ranked from most fatiguing domain (top; Circadian) to least fatiguing domain (bottom; Operational) based on the mean fatigue ranking across all items within the domain. Items are ranked top to bottom from most fatiguing to least fatiguing within domains based on mean fatigue ranking.

DISCUSSION

A subset of commercial European airline M-H pilots completed an anonymous online survey reporting their subjective level of fatigue associated with 40 separate items across four domains.

To our knowledge, this is the first study to focus specifically on sources of fatigue in European M-H operations. The target population conducted north-south operations predominantly in Europe, and thus, did not regularly cross time zones as part of the duty day. M-H pilots in this study returned to their base airport by the end of the duty day and slept in their home environment. Perhaps because of this, pilots reported regularly receiving an average amount of sleep for healthy adults (~7 hours/night).¹⁹ The linear regression results indicated that habitual sleep duration did not predict higher subjective report of fatigue. This finding is in line with the expectation that M-H pilots from a European airline with predominantly north-south travel routes would not experience circadian misalignment or sleep deprivation related to travel across time zones or sleeping in hotel environments.

Pilots reported receiving sufficient sleep but found circadian-related survey items (i.e., early start times, late finishes, and transitioning between a late finish to an early start) as more fatiguing overall compared to items in other domains. This finding supports what is known about the biological circadian rhythm—namely that humans are less alert in the early morning or late at night.²⁰ These schedule features may also limit opportunities for sleep, which would additionally result in fatigue due to sleep restriction.²¹ Importantly, sleep and circadian factors cannot be ignored when investigating M-H operations even though pilots may regularly sleep in the home environment. Sleep deprivation and circadian misalignment can occur in the absence of multi-day travel across time zones, as is the case with social jet lag.²²

The mean fatigue rating for items in the Psychosocial and Environmental domains was higher than the mean fatigue rating for items in the Operational domain. However, it should be noted that the Operational domain contained three times as many items (21 versus seven items) as either the Psychosocial and Environmental domains, including items that would reasonably be

expected to be less fatiguing, such as operating only one flight leg per duty day or working two days consecutively as opposed to three or more days in a row. Operational factors comprise a wide range of scheduling activities and thus, are related to a wide range of subjective report of fatigue. Generally, ratings from the Operational items suggest that longer working hours with fewer breaks was related to higher fatigue. This commonsensical finding provides an ideal target with regards to predicting area of compound fatigue risk using a BMMF.

BMMFs traditionally predict fatigue as a function of time of day and prior sleep history in relation to the work schedule to produce an estimation of alertness.^{11,12} Predicting the impact of factors beyond the concept of fatigue outlined by the three-process model constitutes a challenge for biomathematical modelers. Many of the factors identified in the Operational domain in this study are observable when examining a pilot's work schedule and therefore, could be included in a predictive model. However, the question remains how best to mathematically represent the impact of factors like multiple segments per day or working multiple days in a row in the context of alertness predictions?

In a recent analysis, researchers modified the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model to include the modulation of exogenous factors, collectively called workload, on the endogenous prediction of alertness based on homeostatic and circadian processes in simulated S-H and L-H aviation schedules.¹⁴ The issue with this approach is that the resulting alertness prediction does not differentiate between physiological fatigue or psychological/workload fatigue. The purpose of using a BMMF as part of an airline's FRMS is to provide the airline with a predictive tool that can help them identify and reduce risk of a fatigue-related event occurring during operations.² If a safety manager is presented with a singular output metric for fatigue without context, it would be more difficult to determine

whether there is an increased risk of a fatigue-related event occurring due to sleep deprivation, high workload, circadian misalignment, or operating during the window of circadian low, for example. Multiple overlaying metrics may be preferable in order to fully visualize the risk due to compound fatigue.

Modeling workload as a separate, intervening process is the method employed by the SAFTE-FAST system, which also utilizes the SAFTE model. Triggers can be set to indicate that workload increases over the course of the duty period or when pilots are reliably expected to experience discrete fatigue factors such as multiple segments per duty period or short sit times, independently of time of day or opportunities for sleep. Some of the Environmental fatigue factors, such as cockpit noise, landing terrain at the destination airport, cold weather conditions, and some types of low visibility (e.g., landing after nightfall) may be predicted by information about the aircraft type, time of year, time of day, and geographical locations of the airports within a given roster as well. However, modelers should be cautious when factoring in environmental fatigue since weather is generally unpredictable.

Importantly, pilots reported moderate levels of fatigue (4-6 out of a maximum 10) associated with psychosocial factors. Psychosocial factors vary widely between individuals and cannot currently be accounted for in a population-level BMMF, but can contribute to performance deficits.²³ Psychosocial fatigue factors may be best addressed through initiatives to support crew member mental health, such as peer support. There has not been much focus on the role of pilot mental wellbeing in the context of performance and safety historically, but this is beginning to change.¹⁷ EASA recently mandated airlines to provide support programs for commercial pilots.^{17,24} Organizational support for crew members is not only important for their personal happiness, but also supports aviation safety overall.¹⁷

Wearing a mask to prevent the spread of COVID-19 was listed as the most fatiguing psychosocial factor during this survey. This is in keeping with previous findings that many individuals have difficulty tolerating prolonged mask-wearing and that the psychological aspect of mask-wearing affects mental well-being.¹⁸ At the time of this writing, mask mandates are in decline. However, it is possible that mask wearing may be required again during future waves of COVID-19 or other pandemics. While mask-wearing could be incorporated as a predictable workload factor in BMMFs under mandated circumstances in theory, the psychological stress that mask-wearing causes an individual cannot be predicted in a population-based model.

Pilots in this survey worked M-H operations for a European carrier and were recruited through the company. This constitutes a limitation to generalizability as well as a potential for participation bias when interpreting the survey's results. The survey was administered only in French, which may limit generalizability or reflect a participation bias. One of the next steps is to replicate the survey with pilot populations from different regions and across multiple types of operations in order to create a more nuanced picture of compound fatigue in aviation. Another limitation is that pilots were allowed to complete the survey at their convenience and the study did not collect objective sleep or fatigue data. It is therefore possible that fatigue ratings may have been influenced by a pilots' recent experience or level of sleep deprivation in a manner that cannot be accounted for within the context of this analysis. Despite these limitations, the results of this survey can help inform not only future directions for understanding the impact of compound fatigue on aviator performance, but also highlight areas for improvement in biomathematical modeling of fatigue and fatigue risk management initiatives beyond the use of BMMFs.

In conclusion, fatigue in M-H operations arises from multiple domains. Sleep deprivation may not be a driving factor for fatigue accumulation in M-H but should not be ignored whenever the goal is to understand fatigue. Circadian factors such as waking early or working late may interact with environmental, operational, or psychosocial factors to result in compound fatigue risk. Accounting for risk in relation to compound fatigue may enhance FRMS mitigation strategies. Biomathematical modeling initiatives are just one approach to accounting for compound fatigue. Unpredictable fatigue factors like psychosocial stress or the weather may be mitigated by providing support beyond scheduling or biomathematical modeling.

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