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Evaluating fatigue management regulations for flight crew in Australia using a new Fatigue Regulation Evaluation Framework (FREF)

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ABSTRACT

Flight crew experience fatigue due to sleep loss, circadian desynchrony, early duty start times, long duty periods, high and low workloads, and unscheduled duties. As fatigue is considered a significant safety risk in the air transport industry, the primary approaches to managing fatigue are mandating prescriptive limits for work and rest periods or adopting performance-based fatigue risk management systems (FRMS). However, recent aviation incidents indicate that current regulations may not be adequate to manage the fatigue risk experienced by the flight crew. This study evaluates Australian flight crew fatigue management regulations using a new fatigue regulation evaluation framework (FREF) adapted from Jones et al. (2005). Results show that Australian regulations for flight crew include limits on flight duty period (FDP), off duty period, FDP start time, sleep requirements for flight crew before starting an FDP, high and low workloads, circadian rhythm disruptions, and fatigue awareness. However, there are regulation variations in addressing lengths of sectors and methods to report fatigue, which may need to be reviewed to manage fatigue better. Recommendations are made to consider incorporating these factors into fatigue regulations to ensure a safe air transport system.

1. Introduction

Fatigue is defined as a ‘physiological state of reduced mental and physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person’s alertness and ability to perform safety-related operational duties’ (International Civil Aviation Organisation ICAO, 2016, p. xvi). With regard to aviation flight crew, scholarly articles identify that the following factors can contribute to fatigue: sleep loss, high and low workloads, circadian misalignment, crossing multiple time zones, sector lengths, performing duties that are not rostered, and a lack of awareness of fatigue (Berberich and Leitner, 2017; David-Cooper, 2019; Gander et al., 2014; Marcus and Rosekind, 2017; Missoni et al., 2009; Petrilli et al., 2006). Regulations stipulate prescriptive limits to manage these fatigue factors (prescriptive method) or state the requirements for a performance-based fatigue risk management system (FRMS) (International Civil Aviation Organisation ICAO, 2016; Mannawaduge Dona and Pignata, 2022). Regulators have the option to use one or both fatigue management approaches.

Civil aviation regulations specify limits for flight time/flight duty period (FDP)/duty period, and rest periods based on scientific knowledge and operational experience in the prescriptive method. However, it is a one-size-fits-all approach that does not consider other fatigue-related factors, including sleep requirements during rest periods, the high and low workloads of the FDP, and the number and length of sectors flown (Efthymiou et al., 2021; Gander, 2015; International Civil Aviation Organisation ICAO, 2016). Dawson and McCulloch (2005) state that the prescriptive method focuses on managing physical fatigue rather than the mental fatigue experienced by flight crew. Prescribing work and non-work/rest periods to manage physical fatigue is scientifically defensible and operationally practical, but it is not recognised as an appropriate control to manage mental fatigue. For example, after an FDP, a rest/non-work period to recover from fatigue is prescribed. It is expected that during this rest period, the flight crew will recover from any fatigue accumulated, but this does not account for the mental fatigue associated with factors such as the time of the FDP (night, early morning), and the sleep obtained during the rest period (Dawson and McCulloch, 2005). To address some of these aspects, regulators have added layers such as the length of an FDP based on duty start time, the number of sectors in an FDP, and FDP limits based on in-flight rest breaks under

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prescriptive limits (Gander, 2015). Gander notes that even these added layers do not fully account for the fatigue-related impairments experienced by flight crew. On the other hand, with performance-based fatigue management approaches, air operators use a specialised FRMS that identifies and assesses potential fatigue risks in their own operations, allowing them to identify airline-specific prescriptive limits (Lee and Kim, 2018). There are four functions of a performance-based fatigue risk management approach: 1) measure and access current conditions; 2) model and analyse the fatigue risk; 3) manage and mitigate fatigue risk; and 4) assess and provide feedback (Hulínská and Kraus, 2016). In summary, and as explained through the four functions, it is recognised as a data-driven process, continuously monitoring fatigue risk based on scientific findings and inputs from the organisation's safety management system concerning factors causing fatigue in flight crew (Hulínská and Kraus, 2016; International Civil Aviation Organisation ICAO, 2016; Signal et al., 2008). Fatigue management responsibility is identified as a shared responsibility between the State (aviation safety regulator), air operator, and the individual crew member (Kandera et al., 2019).

In the context of Australian flight crew fatigue management regulations, operators can implement either prescriptive or performance-based approaches to manage flight crew fatigue. In Australia, the government body that regulates aviation safety, the Civil Aviation Safety Authority (CASA), is an independent statutory authority established under the Civil Aviation Act 1988. One of the primary responsibilities of CASA is to ensure operators, service providers, and personnel in air transport adhere to the legislative framework. Australia's legislative framework concerning fatigue management is Civil Aviation Order 48.1 Instrument 2019, effective from July 2021 (Civil Aviation Safety Authority CASA, 2019). CASA states that fatigue management is a shared responsibility between the flight crew, air operators and the CASA. In addition to CASA, the Australian Transport Safety Bureau (ATSB) is an independent body investigating transport accidents and other safety matters. Through independent investigations, ATSB identifies the safety issues for action by the respective organisations, air operators, and/or regulators to manage the safety risk. ATSB also produces reports, briefings, and safety education campaigns.

A study conducted by the ATSB identified that rest obtained at the end of the duty period, rest opportunity provided on standby[1] duty and organisational support in removing flight crew due to fatigue were three aspects related to fatigue in the Australian air transport sector (Australian Transport Safety Bureau ATSB, 2019). These fatigue-related factors were investigated via a 2016 survey by the ATSB which collected data from flight crew engaged in Australian commercial air transport operations (long-haul international, short-haul domestic, regional, charter, aeromedical and helicopter) over a 12-month period. The ATSB received 625 valid responses, of which 133 (21.3%) were flight crew engaged in international long-haul operations and 230 (36.8%) were working in short-haul domestic operations (Australian Transport Safety Bureau ATSB, 2019). The results revealed that 10% of the total sample (25% of those working long haul international) reported less than 5 h of sleep in the prior 24-h period, and 17% of the total sample (30% of those working long haul international) reported less than 12 h of sleep in the previous 48 h. Furthermore, short-haul domestic flight crew identified the need for a longer rest period between standby and a duty period, with 50% reporting that they completed duties whilst on standby. Furthermore, 90% of the total sample reported that management had identified them as experiencing fatigue and as a result, removed them from duty through a formal process. In contrast, only one third reported that they had voluntarily removed themselves from duty because of fatigue (Australian Transport Safety Bureau ATSB, 2019).

With regard to these ATSB findings and recent literature on flight crew fatigue (Caldwell, 2005; Houston et al., 2012; Kandera et al., 2019; Missoni et al., 2009; Powell et al., 2008; Roach et al., 2010, 2012), this paper aims to investigate the following research question: Do CASA regulations on flight crew fatigue (Civil Aviation Order 48.1 instrument 2019) in Australia adequately address flight crew fatigue-related factors such as sleep, rest periods, duty periods, circadian rhythm, standby arrangements, high and low workload periods, and a lack of awareness and education on fatigue?

2. The basis for a fatigue regulation evaluation framework

To investigate the above-mentioned research question, a fatigue regulation evaluation framework (FREF) was developed to analyse Civil Aviation Order 48.1 Instrument 2019. The eight factors detailed by Jones et al. (2005) to compare the laws and regulations in four countries on work hour limits applicable in the transport sector were used as a basis for the FREF. These factors were then augmented through review of more recently published literature and ICAO flight crew fatigue documentation.

2.1. Initial eight factor framework

Jones et al. (2005) compared the regulations on working times for the transport sector (road, rail, sea, air) in Australia, Canada, the United Kingdom (UK), the United States of America (USA) and the European Union (EU). They then assessed these regulations against eight factors derived from Dawson et al. (2001) and the National Transport Safety Bureau (1999) report on fatigue in transport workers (Dawson et al., 2001; National Transport Safety Board NTSB, 1999). Dawson et al. (2001) presented findings from an expert group comprising sleep, shift work and road safety experts appointed by Australia's National Road Transport Commission, the ATSB, and the New Zealand Land Transport Safety Authority. The aim of their study was to set evidence-based design principles to consider when designing future fatigue regulations. By reviewing the published literature they identified the need to provide a flexible and practicable framework to manage the fatigue experienced by transport workers, and the group agreed on important considerations in fatigue management for transport workers that included the: requirement for minimum sleep periods; time (day or night) of duties and sleep opportunities; cumulative nature of fatigue and sleep loss; duration of work, especially when performed at night-time; and use of short breaks within work periods as a countermeasure.

Jones et al. (2005) also examined an evaluation of the U.S. Department of Transportation work in 1990 to investigate accidents due to operator fatigue that occurred in the 1980s. Recommendations from this work included the need to undertake further research on the effects of fatigue, sleepiness, sleep disorders and circadian factors on the transport worker safety across road, rail, aviation, and marine modalities. It was also recommended that awareness programmes be conducted to educate transport workers on management on shift work, work and non-work periods and the requirement of maintaining good health, a healthy diet and proper rest. The need to review and update the regulations on work periods in transport industries to stay current with recent research on fatigue and sleep requirements was highlighted.

Based on the abovementioned recommendations, Jones and colleagues (2005) determined that the following eight factors were related to fatigue in transport workers: (1) Time of day; (2) Circadian rhythm; (3) Duration of opportunity for sleep; (4) Sleep quality; (5) Predictability; (6) Sleep debt; (7) Time on task; and (8) Short breaks. The researchers used these factors to undertake a comparative analysis of the fatigue regulations of four countries and one region. For example, time of day was evaluated via the question "Do the regulations address work at night?" that assesses whether the regulations of these four countries and region includes provisions for work at night.

When examining the eight factors, it is evident that recent developments in the air transport industry, regulatory documents, and new scholarly articles (Caldwell, 2005; Houston et al., 2012; Kandera et al.,

[1] "A defined period of time during which a flight or cabin crew member is required by the operator to be available to receive an assignment for a specific duty without an intervening rest period" (International Civil Aviation Organisation ICAO, 2016, p. xvi).

Table 1
Acronym glossary.

ATSB	Australian Transport Safety Bureau
CASA	Civil Aviation Safety Authority
DP	Duty Period
FCM	Flight Crew Member
FDP	Flight Duty Period
FREF	Fatigue Regulation Evaluation Framework
FRMS	Fatigue Risk Management Systems
FT	Flight Time
ICAO	International Civil Aviation Organisation
IFR	In-Flight Rest
NTSB	National Transportation Safety Board
RP	Rest Period
S	Standby
SARPs	Standards and Recommended Practices
SB, SA	Sleep Before, Sleep After
WOCL	Window of Circadian Low

2019; Missoni et al., 2009; Roach et al., 2010) include additional contemporary fatigue-related factors that can be used to assess fatigue management regulations. Therefore, the eight factors and the questions for each of the eight-factor criteria were re-defined, adapted, and then extended into the new FREF as outlined in the following section.

3. Materials and methods

Due to the number of acronyms used in this research area, a glossary is provided in Table 1.

3.1. Updating the initial eight factor framework

Fig. 1 illustrates the process that was followed to develop the FREF. The first Step involved studying the eight factors to determine which factors were relevant for flight crew. In Step two, the following types of documentation were used to augment the eight factors reported by Jones and colleagues (2005) to develop the new FREF: (1) Standards and Recommended Practices (SARPs) and guidance material on flight crew fatigue published and amended by ICAO between 2016 and 2022; and (2) over 70 recently published scholarly papers on factors related to flight crew fatigue. The scholarly articles were accessed through the University of South Australia library catalogue and databases such as ScienceDirect, Scopus, PubMed, Taylor & Francis Online using search terms including “fatigue”, “flight crew fatigue” and “factors causing flight crew fatigue.”

Factors arising from recent literature and ICAO documentation were categorised as being related to the existing eight factors (Jones et al., 2005), or as new factors. Some of the factors were combined and re-named. New questions were added to address factors arising as required. For example, existing factors from Jones et al., (1) Time of day and (2) Circadian rhythm were combined and included as a single factor (B in the FREF, Table 2). Then, the next step involved determining if any factors in the existing criteria could be further explored by adding additional questions to the FREF. When new contributing factors were identified in the extant literature and regulatory documents, (for example, circadian rhythm disruptions due to window of circadian low (WOCL), work at night, early start times and time zone crossing

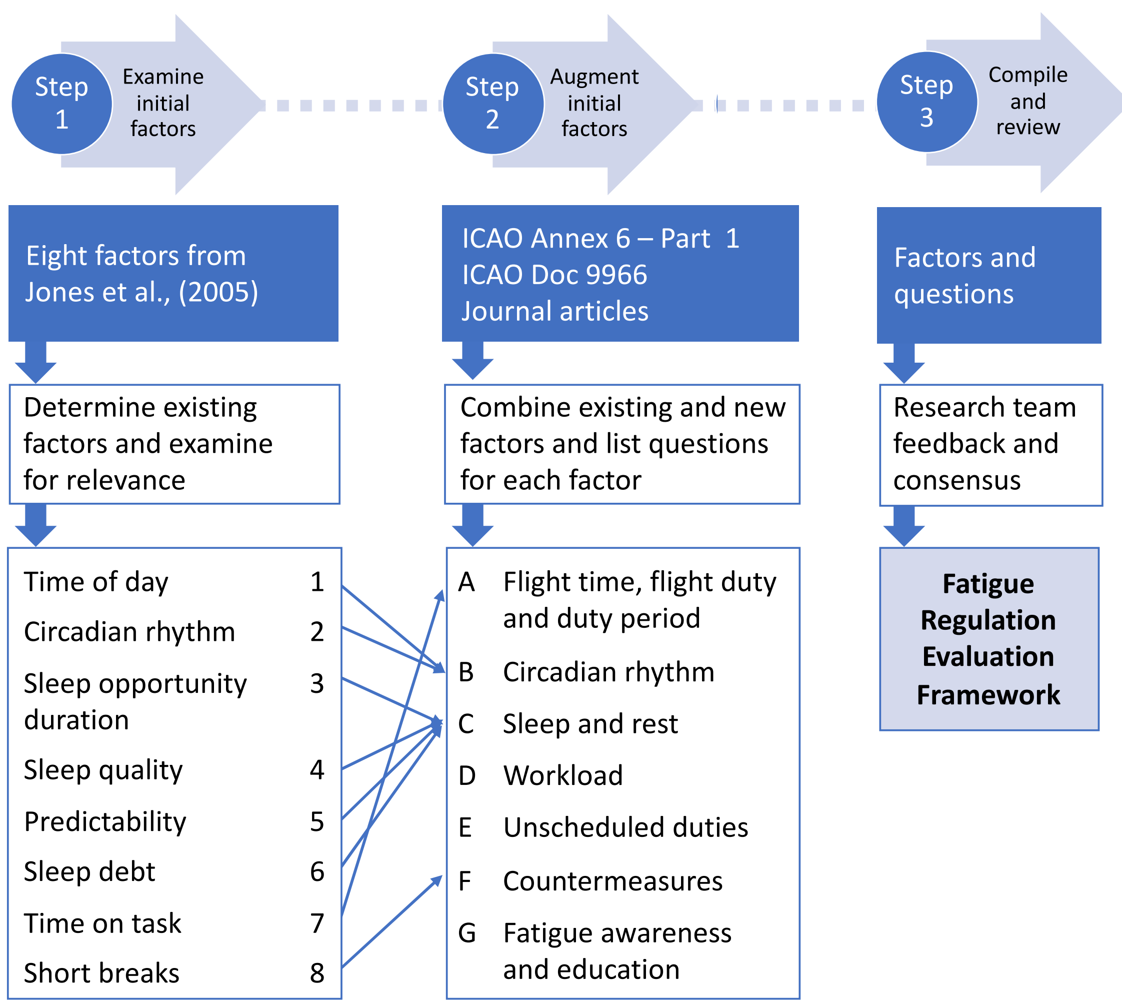

Fig. 1. Fatigue Regulation Evaluation Framework (FREF) adapted from Jones et al. (2005) eight factors.

Table 2
Material used to develop the Fatigue Regulation Evaluation Framework (FREF).

FREF	ICAO Annex/ICAO Document	Study
A. Flight time, flight duty and duty period	International Civil Aviation Organisation. (2016), International Civil Aviation Organisation. (2022)	Caldwell (2005), Caldwell et al. (2009), Cabon et al. (2002), Karanikas & Nederend. (2019), Powell et al. (2010), Schmid & Stanton (2020), Thomas and Ferguson (2010), van Drongelen et al. (2017)
B. Circadian Rhythm	International Civil Aviation Organisation. (2016)	Caldwell (2005), Caldwell et al. (2009), Caldwell, (2012), de Mello et al. (2008), Dawson and Fletcher. (2001), Efthymiou et al. (2021), Gander et al. (2013), Karanikas & Nederend. (2019), Missoni et al. (2009), Phillips et al. (2017), Powell et al. (2008), Reis et al. (2016), Signal et al. (2008), Schmid and Stanton (2020), Vagner et al. (2018), Williamson et al. (2011), Yen et al. (2009)
C. Sleep and Rest	International Civil Aviation Organisation. (2016), International Civil Aviation Organisation. (2022)	Bourgeois-Bougrine et al. (2003), Cabon et al. (2012), Dawson et al. (2001), Dai et al. (2020), de Mello et al. (2008), Efthymiou et al. (2021), Gander. (2015), Jerman & Meško. (2018), Karanikas & Nederend. (2019), Lee & Kim. (2018), Schmid & Stanton. (2020), Steiner et al. (2012), Vagner et al. (2018), Williamson et al. (2011)
D. Workload	International Civil Aviation Organisation, (2016)	Berberich & Leitner. (2017), Missoni et al. (2009),
E. Unscheduled duties	International Civil Aviation Organisation. (2016)	David-Cooper (2019), Houston et al. (2012)
F. Countermeasures for fatigue	International Civil Aviation Organisation. (2016)	Caldwell et al. (2009), Gander et al. (2014), Kandera et al. (2019), Keith & Alexander (1997), Missoni et al. (2009), Petrilli et al. (2006), Petrilli et al. (2006), Phillips et al. (2017), Roach et al. (2010, 2011), Schmid & Stanton (2020), Yen et al. (2009)
G. Awareness and education on fatigue	International Civil Aviation Organisation. (2016)	Kandera et al. (2019), Marcus & Rosekind. (2017), Signal et al. (2008)

(eastward and westward)) additional questions and sub-questions were developed under Factor B to evaluate whether all the elements of circadian rhythm that can result in flight crew fatigue are included in the regulations. As another example, Factor G (Time on task), which evaluated the maximum period of the primary tasks of a transport worker in the initial eight factors, was separated into constituent elements specific to flight crew in the aviation industry and recategorised in the FREF in Factor A, question 1: "Do the regulations specify a maximum flight time/flight duty period/duty period limit(s) within 24 h?" The questions relating to each factor are presented in the tables in the Results Section.

The process of adapting factors from the initial eight factors to the final list in the FREF is depicted through the connecting arrows between the two sets of factors in Fig. 1. Of note, all the initial eight factors were included in the FREF but were combined into four factors due to their similarity. The distinct elements represented by the initial factors were instead represented using questions within the factor. This allowed for inclusion of concepts arising from the literature and documentation through the addition of factors and questions within each factor. For example, duration of opportunity for sleep, sleep quality, predictability, and sleep debt were combined and re-named as sleep and rest in the FREF, with 11 questions created for the sleep and rest factor. The adapted and expanded factors and related questions were then discussed with the research team experienced in sleep and fatigue research in the transport industry. After integrating feedback, the final FREF framework was developed in Step 3 listing the new seven fatigue-related criteria as A. flight time, flight duty and duty period, B. circadian rhythm, C. sleep and rest, D. workload, E. unscheduled duties, F. counter measures for fatigue, and G. awareness and education on fatigue.

3.2. Using the FREF to evaluate regulations for flight crew fatigue in Australia

The FREF was then used to evaluate the Civil Aviation Order 48.1 Instrument 2019, which specifies the limits and requirements for air operations in Australia. The regulations stipulate fatigue management regulations for all flight operations (single pilot, multi-pilot, medical transport, emergency service, flight training, aerial work). Regulations in Appendix 1, 2 and 3 of the Civil Aviation Order, applicable to international commercial operation regulations were also examined. The evaluations were recorded using a pattern scale (LT Dwn Diagonal, LT vertical and LT trellis). If the regulation satisfactorily answered each question or sub-question, it was marked in LT dwn diagonal pattern to reflect agreement. If an answer to a question could not be found in the regulations, it was marked in LT vertical to reflect that there was no information to answer that specific question in the regulations. If the information in the regulation provided a partial answer to the FREF category question, LT trellis pattern was used to reflect that the question was not sufficiently addressed in the regulations.

4. Results and discussion

This section details the results of evaluating CASA's CAO 48.1 instrument (2019) against the FREF.

4.1. Flight time, flight duty period and duty period

The regulators in the aviation industry stipulate limits on flight time (FT), flight duty period (FDP) and duty period (DP) to manage the fatigue risk experienced by the flight crew. ICAO recommends countries prescribe maximum work periods and minimum rest periods considering factors such as extended duty periods, night flying, time zone crossing, and sector lengths (International Civil Aviation Organisation ICAO, 2016). FREF Factor A was used to evaluate whether the regulations on flight crew fatigue management include these maximum limits on work periods. The results, summarised in Table 3, show the results for each question within Factor A. Civil Aviation Order 48.1 instrument 2019 stipulates the requirement that a flight crew member (FCM) "may only be assigned an FDP that is between the following times: (a) the earlier of the following: (i) the beginning of morning civil twilight on a day; (ii) 0700 h local time on the day; (b) 0100 h (local time at the location where the FDP commenced) on the following day" (Civil Aviation Safety Authority CASA, 2019, p. 24). However, "if the FDP begins before 0600 h or after 1400, it must be a maximum of 8 h" (Civil Aviation Safety Authority CASA, 2019, p. 24). For multi-crew operations, if the FCM is acclimatised ("commencing a FDP or an off-duty period in a location different to the local time zone of the flight crew in less than 2 h and the FCM remained in an acclimatised state since he or she was last acclimatised"), a grid is used to specify the maximum FDP based on the number of sectors and FDP start time, i.e., for a FDP starting between 0500 and 0559 if the flight crew is rostered for four sectors, the maximum FDP can be up to 10.5 h (Civil Aviation Safety Authority CASA, 2019, p. 12). As shown in Table 3, the Australian regulations stipulate that the maximum FDP limits consider the start time for multi-crew operations. A similar grid for non-acclimatised ("when commencing a FDP or an off-duty period in a location different to the local time zone of the FCM in an unknown state of acclimatisation") is also included in the regulation (Civil Aviation Safety Authority CASA, 2019, p. 12).

The FDP information in the grid also indicates the number of sectors (how many origins and destination trips) flight crew members can

Table 3
Results of CAO 48.1 on factors related to flight time, flight duty period and duty Period.

Question and sub question number	Question and sub question	Results based on CAO 48.1
A1	Maximum FT/FDP/DP	Answered Satisfactorily
A2	Start time of maximum FT/FDP/DP	Answered Satisfactorily
A3a	Flight crew complement	Answered Satisfactorily
A3b	Sector length (SH, MH, LH, ULR)	No information found in the regulations
A3c	Number of sectors	Answered Satisfactorily
A4a	Consecutive total work periods (seven days)	Answered Satisfactorily
A4b	Consecutive total work periods (28/30 consecutive days)	Answered Satisfactorily
A4c	Consecutive total work periods (365 consecutive days / 12 calendar month)	Answered Satisfactorily
A5	Variation of FT/FDP/FT	Answered Satisfactorily
A6a	Duration of an extension for variation	Answered Satisfactorily
A6b	Method of an extension for variation	Answered Satisfactorily
A7a	Circumstances in which the variations can be used	Answered Satisfactorily
A7b	Operations in which variations may be applied	Answered Satisfactorily
A7c	Mitigation strategies to address increased fatigue	Answered Satisfactorily
A7d	Variation limits	Answered Satisfactorily
A8	Flight crew fatigue-related records	Answered Satisfactorily
A9	Positioning/deadhead transportation	Answered Satisfactorily
A10	Roster for flight crew	Answered Satisfactorily
A11	Split duty	Answered Satisfactorily

Answered Satisfactorily; No information found in the regulations; Not sufficiently addressed

perform corresponding to the start time of their FDP. The regulations state a cumulative 60-duty hours limit for flight crew in seven days. However, the flight crew members can perform a maximum of 100 flight time (FT) hours in any 28 days (Civil Aviation Safety Authority CASA, 2019). In 365 days, a maximum of 1000 FT hours can be performed by flight crew. As marked in Table 3, the regulations do not specify any FDP limits or requirements applicable for operations based on the sector length, such as short, medium, long-, and ultra-long-haul operations. The regulations stipulate the applicable requirements for operators and flight crew members when extending the FDP limits, including the method to extend the FDP, circumstances and operations that arise to extend the FDP limits, number of hours the FDP can be extended, and the fatigue mitigation strategies in the event of extended FDPs. Rosters, records of duty periods, flight times, rest periods, and standby arrangements should be maintained by the air operators for 5 years as specified by CASA in Part 3 of CAO 48.1 (Civil Aviation Safety Authority CASA, 2019). After completion of an FDP, time spent by the flight crew in positioning to a suitable location is considered as a part of the FDP, and it should be considered in determining the applicable off-duty periods. Air operators are permitted to increase the FDP by 4 h, not exceeding 16 h, if the FDP period includes a split duty rest period of 4 h with access to suitable sleeping accommodation (Civil Aviation Safety Authority CASA, 2019).

The results indicate that Australian regulations to manage flight crew fatigue include maximum limits on FDP. When mandating these limits, FDP start times, sectors operated, consecutive work periods, extension to FDP, flight crew complement, split duty periods, positioning requirements and record maintenance are considered. The regulations address many of the elements associated with FDP limitations satisfactorily as illustrated in Table 3. As identified by Missoni et al. (2009) it is vital to consider crew composition, number of sectors, flight range, duration of FT, FDP, DP, time zone crossing, night flying, rest before a flight and night sleep in regulations to manage flight crew fatigue. Most of these factors, except sector length, are addressed in the CAO 48.1 in prescribing limits on FDP. The literature suggests notable differences in operational environments in short and long-haul flights which indicates the importance of addressing sector length in relation to maximum flight duty periods (Bourgeois-Bougrine et al., 2003).

4.2. *Circadian rhythm*

Flight crew members carry out flight duty periods during periods the circadian body clock would be essentially asleep, thus considering factors such as FDP during the window of circadian low, early duty start times, late night finishes and long duty periods are essential as they contribute towards flight crew fatigue (Caldwell, 2005; Gander et al., 2014). As explained in this section, CAO 48.1 instrument 2019 addresses circadian rhythm and related aspects satisfactorily.

By addressing time zone crossing, the window of circadian low (WOCL), early morning and late-night start times, the regulations sufficiently address the requirements for circadian rhythm when assigning FDPs for flight crew. The regulations include a provision on the window of circadian low that states a flight crew should only be assigned a maximum of three consecutive early starts (Civil Aviation Safety Authority CASA, 2019). If a flight crew member is rostered for a FDP within the WOCL consecutively more than three times then the FCM should be provided with an off-duty period that includes a local night before assigning another new FDP (Civil Aviation Safety Authority CASA, 2019). A fourth and fifth duty period can be assigned with early morning starts that infringe the WOCL if the FDP in the early fourth start is reduced by 2 h and subsequently if the early fifth start is reduced by 4 h (Civil Aviation Safety Authority CASA, 2019).

As shown in Table 4, CAO 48.1 addresses circadian rhythm (CR), performance decrements associated with CR disruptions, work at night, early start times, time zone crossing and the number of landings when assigning FDPs. The regulations indicate that a FCM may only be assigned an FDP following the beginning of morning twilight, 0700 h local time. If the FDP starts before 0600 h, it should be limited to a maximum of 8 h. This provision is in Appendix 1 of CAO 48.1 and applies to all operations. In addition, the maximum FDP a FCM can perform in multi-crew operations corresponds to the FDP start time and number of sectors rostered. This grid, applicable in multi-crew operations, again addresses the requirements under circadian rhythm in detail, including the number of sectors/landings that FCMs can perform in an FDP. Addressing the requirement of the number of time zones

Table 4
Results of CAO 48.1 on Factors related to Circadian Rhythm.

Question and sub question number	Question and sub question	Results based on CAO 48.1
B1a	Circadian rhythm	Answered Satisfactorily
B1b	Associated performance decrements	Answered Satisfactorily
B2a	The window of circadian low (WOCL 0200 to 0600)	Answered Satisfactorily
B2b	Work at night	Answered Satisfactorily
B2c	Early start-up	Answered Satisfactorily
B3a	Time zones crossed (WF/EF)	Answered Satisfactorily
B3b	Number of landings/flight stages	Answered Satisfactorily

Answered Satisfactorily | No information found in the regulations | Not sufficiently addressed

Table 5
Results of CAO 48.1 on factors related to sleep and Rest.

Question and sub question number	Question and sub question	Results based on CAO 48.1
C1a	Sleep before/after a FT/FDP/DP	Answered Satisfactorily
C1b	Sleep for two consecutive nights	Answered Satisfactorily
C2a	Rest before/after a FT/FDP/DP	Answered Satisfactorily
C2b	Minimum rest duration (six/seven/eight/nine/twelve)	Answered Satisfactorily
C2c	Rest away from home	Answered Satisfactorily
C2d	Extended rest periods to preclude cumulative fatigue	Answered Satisfactorily
C2e	Rest based on flight duration/length for the flights (SH, MH, LH, ULR)	No information found in the regulations
C2f	Rest period based on extended FT/FDP/DP	Answered Satisfactorily
C2gi	Impact of time zone crossing	Answered Satisfactorily
C2gii	Night operations	No information found in the regulations
C2giii	Travel time spent by the flight crew in transit between the place of rest and place of reporting for duty	No information found in the regulations

Answered Satisfactorily | No information found in the regulations | Not sufficiently addressed

crossed eastward and westward, the regulations consider that the applicable rest period (home base and away from home base)[2] should consider whether the flight is performed eastward/westward and subsequently adds to the displacement time when calculating the off-duty period (Civil Aviation Safety Authority CASA, 2019). Thus, the Australian regulation fully address circadian rhythm-related factors related to flight crew fatigue. As fatigue caused by circadian disruption impairs human decision-making, reaction time, long-term and short-term memory, and communication skills it is vital to consider circadian rhythm disruption during the design of flight crew schedules to reduce the impact on flight crew (Marcus and Rosekind, 2017; Petrilli et al., 2006).

4.3. Sleep and rest

Research widely acknowledges that flight crew experience fatigue and performance decrements due to individual differences identified as irregular sleep patterns, inadequate sleep and rest periods to overcome cumulative effects of fatigue, and extended wakefulness (Jerman and Meško, 2018). Therefore, it is vital to address these sleep and rest issues in the regulations to mitigate the risk of performance decrements experienced by flight crew. The CAO 48.1 addresses sleep and rest aspects contributing to flight crew fatigue satisfactorily, as shown in Table 5. Rest periods based on sector length and night operations are some factors not addressed in the regulations but are considered important in the literature.

As per CASA's CAO 48.1, air operators should allow "8 h of sleep opportunity within 10 h immediately before the start of a FDP away from home-base" and "12 h immediately before the start of a FDP at home base" (Civil Aviation Safety Authority CASA, 2019, p. 26). The regulations further address the rest requirements through off-duty periods for all operations in Appendix 1 and for multi-crew operations in Appendixes 2 and 3. As shown in C2b of Table 5, the sub question on flight crew obtaining two consecutive nights of sleep to recover from sleep debt is marked as satisfactory. The regulations state before commencing an FDP, flight crew must have 36 consecutive hours off-duty which should include two local nights to preclude cumulative fatigue (Civil Aviation Safety Authority CASA, 2019).

Flight crew must be provided with a rest period of 12 h at home base (principal place of business of the airline) and 10 h away from home base in 24 h (Civil Aviation Safety Authority CASA, 2019). The regulations also require air operators to consider the cumulative effects of fatigue and include an "off-duty period of 36 consecutive hours in 168 h before the end time of an assigned FDP and six off-days in 38 consecutive days" (Civil Aviation Safety Authority CASA, 2019, p. 35). If a duty time after completion of the "FDP exceeds 12 h, the subsequent off-duty period should be the addition of the FDP and 1.5 times the period that exceeded the FDP" (Civil Aviation Safety Authority CASA, 2019, p. 34). If the FCM is in an unknown state of acclimatisation, the off-duty period should add "14 h and 12 h and 1.5 times of the FDP that exceeded the 12

[2] The location nominated by the operator to the crew member from where the crew member normally starts and ends a duty period or a series of duty periods (International Civil Aviation Organisation, 2016, p.128).

Table 6
Results of CAO 48.1 on factors related to Workload.

Question and sub question number	Question and sub question	Results based on CAO 48.1
D1	Workload (LWP, HWP, LDP, RA)	
D2	Workload with flight duration/lengths (SH, MH, LH, ULR)	

Answered Satisfactorily | No information found in the regulations | Not sufficiently addressed

Table 7
Results of CAO 48.1 on factors related to unscheduled Duties.

Question and sub question number	Question and sub question	Results based on CAO 48.1
E1	Start and end time of standby/reserve	
E2	Maximum duration for standby/reserve	
E3	Standby/reserve duties scheduled in a predictable manner	
E4a	Airport standby followed by FDP considered a part of the duty	
E4b	Airport standby followed by FDP to calculate the minimum rest	
E5	Standby at an accommodation	
E6	Protocol/facilities/interruptions (non-urgent work calls) on standby	

Answered Satisfactorily | No information found in the regulations | Not sufficiently addressed

h period" (Civil Aviation Safety Authority CASA, 2019, p. 34). The impact of time zone crossing is considered in determining the rest periods by assigning an additional 3 h for travelling west and 2 h for travelling east based on the time zone of the FCM's homebase. The regulations do not address any rest period limits based on the type of flight (short-, medium-, long-, ultra-long haul), as indicated in C2e of Table 5. Furthermore, rest periods for night operations and travel time spent by the flight crew in transit between the place of rest and place of reporting are also not considered under the rest period limits.

4.4. Workload

Research indicates that accounting for the workload before and after the flight, landing and take-off of the flight and en route is crucial as some of these phases require higher levels of attention and communication (Berberich and Leitner, 2017; Missoni et al., 2009). Berberich and Leitner state that flight crew experience fatigue due to the high and low workload which clearly indicates the importance of addressing workload as an essential factor related to flight crew fatigue.

Workload is an area that the regulations do not address directly by stipulating what air operators need to consider when rostering FCM for an FDP. However, the regulations indirectly address the workload of FCM as through inclusion of the maximum FDP limits corresponding to the FDP start time and sectors that can be performed within that period (Civil Aviation Safety Authority CASA, 2019). The regulations did not directly consider the flight duration/length when determining high and low workload demands in different types of flights (Table 6).

4.5. Unscheduled duties

Unscheduled duty occurs when flight crew are required to be available for duty at short notice in addition to their scheduled duty periods. The air transport industry often involves unpredictable operational demand due to the nature of the industry. Literature on standby/reserve states that factors such as 1) sleep opportunity during standby/reserve; 2) length of standby periods and notification periods; and 3) standby/reserve counted towards duty in the context of standby/reserve duties are considered as important in unscheduled duties (David-Cooper, 2019; Houston et al., 2012). Flight crew members often identify fatigue due to unscheduled duties because of the nature of these duties. The regulations satisfactorily address some elements related to standby duties as discussed in this section, but further consideration should be given to add more details in the regulations to ensure that air operators are provided with more information on adequate facilities to sleep/rest (including adequate ventilation, comfortable bed, minimal interruptions during the rest period, for example the handling of non-urgent work calls).

The CAO 48.1 addresses the requirement of notifying the start and end time of standby duties sufficiently in advance and predictably, as indicated in E1 of Table 7. Part 3 of the regulations states that air operators must publish rosters well in advance, including standby periods allowing FCMs to plan their rest. As per Appendix 2 of the CAO 48.1, air operators should only place a flight crew member on standby for a maximum of 14 consecutive hours (Civil Aviation Safety Authority CASA, 2019). Also, as any standby arrangement is considered a duty, it was interpreted that the rest period applicable after a duty period is applied for a flight crew member on standby. The regulations do not include any direct provision that states the accommodation arrangements, facilities, and protocol for handling interruptions by a flight crew member while on standby (Civil Aviation Safety Authority CASA, 2019). When applying the FREF to evaluate the regulations, it was considered that these requirements were covered under split duty rest, where the regulations state that the FCM should have access to suitable sleeping accommodations. Therefore, the regulations partially address the question of accommodation during standby, and protocol/facilities/interruptions at standby, as shown by the LT trellis pattern in E5 and E6 (Table 7).

4.6. Countermeasures for fatigue

In-flight napping, sleep and rest are widely used common coping strategies identified by research and implemented by air operators to

Table 8
Results of CAO 48.1 on factors related to countermeasures for Fatigue.

Question and sub question number	Question and sub question	Results based on CAO 48.1
F1	In-flight rest/breaks/napping	Answered Satisfactorily
F2a	Physical facility requirements for in-flight rest/breaks/napping	Answered Satisfactorily
F2b	Duration of in-flight rest/breaks/naps	Answered Satisfactorily
F3	Protocol for in-flight rest/breaks/napping	Answered Satisfactorily

Answered Satisfactorily   No information found in the regulations   Not sufficiently addressed

overcome fatigue experienced by FCM in flight (Roach et al., 2011). These strategies are considered as countermeasures for fatigue (Caldwell et al., 2009; Roach et al., 2010). A study that examined the inflight sleep/wake and work/rest data from 301 flight crew members for two weeks during long-haul flight patterns identified that if the flight crew were highly fatigued, an average of 3.7 h of in-flight sleep was obtained. If the flight crew experienced low fatigue during the duty period, an average of 1.8 h of sleep was obtained (Roach et al., 2011). The rests/breaks taken by the flight crew during duty periods could be used more effectively as only 54% of flight crew converted their break into a sleep opportunity when the fatigue likelihood was extreme. The study's results indicate that several environmental factors (bed comfort, light, noise level, warmth, and dryness of the cabin air) prevent in-flight sleep (Missoni et al., 2009; Roach et al., 2010). Subsequently a recent study conducted on 19 commercial pilots flying on long-range sectors for 12–16 h on four flight segments (Australia-Asia, Asia-Europe, Europe-Asia, and Asia-Australia) with layovers in between collected data on their sleep/wake history using actigraphy, sleep/work logbooks, the Samn-Perelli self-report fatigue scale, and a 5-min psychomotor vigilance task (PVT) (Rempe et al., 2022). The flight crew who participated in the study obtained an average of 8.2 ± 1.7 sleep per 24 h across the study period. The findings of this study showed that fatigue ratings were highest, and the PVT mean response rate was lowest at the end of each flight. The highest fatigue ratings were demonstrated at the end of the last flight segment which indicated that in-flight sleep is essential for flight crew to be alert and perform during the flight. It is of interest that the sleep results obtained by flight crew engaged in long range (LR) and ultra long range (ULR) flights in the Rempe et al. (2022) study is higher (8.2 ± 1.7h) compared to the in-flight sleep obtained by flight crew in the Roach et al. (2011) study (3.7–1.8h). Nevertheless, both studies indicate that in-flight sleep is essential as a countermeasure for flight crew fatigue with adequate facilities such as bed comfort, light and noise level, warmth, and dryness of cabin air.

The CAO 48.1 specifies that if more than one flight crew member is on flight duty, FCMs can obtain in-flight rest in an augmented crew operation (Civil Aviation Safety Authority CASA, 2019, p. 3). The rest period corresponds to the FDP start time of the FCM and the number of crew members available in the flight deck. For example, if the "FDP starts between 0700 and 1059 h and an additional two FCMs are available in the flight deck, the flight crew can obtain a rest of up to 18 h in a class 2[3] rest facility" (Civil Aviation Safety Authority CASA, 2019, p. 29). Physical rest facility requirements are clearly stated in the regulations adopting the ICAO classification for classes 1, 2 and 3. The regulations satisfactorily address all the FREF categories under in-flight rest/breaks/napping, as shown in Table 8 below. CAO 48.1 instrument 2019 address in flight rest opportunity with the relevant physical facilities that should be provided satisfactorily as discussed in the results and illustrated in Table 8 below.

4.7. Awareness and education on fatigue

The NTSB identifies raising awareness of human fatigue, sleep, and circadian rhythms to address the problem of fatigue experienced in the transport sector (Kandera et al., 2019; Marcus and Rosekind, 2017). Furthermore, recent research complements this by indicating that these fatigue awareness and education programmes help identify fatigue, which is a preventive measure to successfully mitigate the risk (Marcus and Rosekind, 2017; Rudin-Brown and Rosberg, 2021). Therefore, education and training on fatigue is an important aspect for flight crew to manage. The regulations address this component satisfactorily by stating an extensive training programme for flight crew fatigue management.

Part 3, Section 15 of the Australian regulations state that flight crew are required to be equipped with "knowledge and training to identify their fatigue, fatigue-related impairments, the risk associated with fatigue, obligations, and procedures for handling fatigue under the air operators flight operations manual" (Civil Aviation Safety Authority CASA, 2019, p. 21).

As per the CAO 48.1 air operators are also responsible for including in the flight operations manual, the requirement of training and awareness of fatigue. This is an area that the regulations addressed comprehensively including provisions for the recurrent training requirements after the initial training. Although the regulations state that the flight crew should be equipped with knowledge and awareness to identify fatigue, the regulations could be augmented to suggest how it might be reported to the air operator. Therefore, Question G2 of Table 9 is marked as not sufficiently addressed.

To address the research question examined in this current study, the flight crew fatigue management regulations in Australia (CAO 48.1 Instrument, 2019) satisfactorily address the factors of sleep, rest periods, duty periods, circadian rhythm, unscheduled duties (standby), high and low workload, and the education and awareness of fatigue.

The results indicate that CAO 48.1 Instrument 2019 includes limits for FDP and off-duty periods. These limits consider FDP start times, sectors performed, and the flight crew complement. Also, the consecutive work periods, the extension of FDP periods, publishing the rosters allowing sufficient time to plan the rest and maintaining records of the FDP and off-duty periods are also addressed adequately in the regulations. In addition, essential factors such as circadian rhythm and its associated factors such as work at night, early duty start times, WOCL, and time zone crossing are also addressed in the regulations. The following are also satisfactorily addressed in the regulations: sleep before/after a flight, two consecutive nights sleep, rest period limits, rest away from home, extended rest periods to preclude cumulative fatigue, rest period based on time zone crossing, high and low workload periods, start and end time of standby duties, duration of standby, in-flight rest duration, physical facility requirements for in-flight rest, protocols for

[3] seat in an aircraft cabin that: (i) is fit for the purpose of an FCM obtaining sleep in a horizontal or near-horizontal sleeping position; and (ii) is separated from passengers by at least a curtain that provides darkness and some noise mitigation; and (iii) is reasonably free from disturbance by passengers or crew members (Civil Aviation Safety Authority, 2019, p.4).

Table 9
Results of CAO 48.1 on factors related to awareness and education on Fatigue.

Question and sub question number	Question and sub question	Results based on CAO 48.1
G1	Fatigue symptoms/Effects of fatigue/countermeasures for fatigue/limitations on flight time/flight duty period/rest period	Answered Satisfactorily
G2	How to report/who to report/what to report if flight crew experience fatigue	Not sufficiently addressed

Answered Satisfactorily No information found in the regulations Not sufficiently addressed

in-flight rest, and education on identifying fatigue symptoms/effects/countermeasures.

However, some variability exists in addressing the sector length in short-, medium-, long-, and ultra-long-haul flights when assigning flight duty, off-duty periods, and workload in the cockpit. Recent literature shows that sector length is essential to flight crew fatigue (Missoni et al., 2009; Powell et al., 2008). A 2003 study conducted from January 1 to March 31, with data gathered from flight crew operating Boeing 737-300s, 767s and 747-400s, found that the time of the day that the FT/FDP/DP starts and the number of sectors operated contributed towards flight crew fatigue (Powell et al., 2008). Furthermore, the regulations identify the importance of identifying FCM fatigue and refraining from performing flight duties but does not indicate a method of reporting if a FCM is fatigued. Regulations could be augmented to address this directly to support FCMs to take action should they feel fatigued and unfit to operate the FDP assigned to them. Raising awareness and education on fatigue was identified as an effective fatigue mitigation strategy back in 1990 in an NTSB study and in recent literature addressing the fatigue experienced by those in the transport sector (Kandera et al., 2019; National Transport Safety Board NTSB, 1999). The regulations satisfactorily include raising awareness and educating FCM on fatigue, its impairments, causes, and risk associated through initial and recurrent training provided by air operators (Civil Aviation Safety Authority CASA, 2019).

5. Strengths and limitations

A strength of this study is the use of current and relevant regulations and academic literature. The first author relied on their existing broad knowledge of international aviation fatigue management regulations to assist in the interpretation of regulatory provisions in the CAO 48.1. The categorisation of the regulations as addressing, not addressing, or not sufficiently addressing questions and sub-questions under the seven factors in the FREF relied on discussion and consensus from the research team. The scope of this project was a mapping of the regulations onto identified factors influencing flight crew fatigue. The aim was to examine whether these factors were addressed sufficiently. It is important to note that this was not an examination of the effectiveness of the regulations, which would require a much broader study. This project represents a first step in developing and applying a framework. Next steps could include applying the framework across regulations internationally as a basis for comparison. Further research could also be conducted in collaboration with regulatory authorities, operators, and crew to improve the usability of the FREF.

6. Conclusion

This study evaluated the fatigue management regulations included in Appendix 1,2 and 3 in CAO 48.1 instrument 2019 of flight crew engaged in commercial flight operations in Australia. The results indicate that the regulations satisfactorily address essential factors related to flight crew fatigue, such as limits on FDP and off-duty periods, sleep and rest periods, workload, in-flight rest, circadian rhythm, unscheduled duties such as standby, and awareness and education on fatigue for flight crew members. Factors such as sector length (short-, long-, medium-, and ultra-long haul) and reporting methods of flight crew fatigue were identified as having some variability in the existing regulations in relation to the FREF. These factors are essential and important factors related to flight crew fatigue as shown by existing research and the ICAO SARPs and guidance material. Further consideration could be given to representing these factors more directly in the regulations.

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CRediT authorship contribution statement

Chanika D. Mannawaduge: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Silvia Pignata:** Validation, Writing – review & editing, Supervision. **Siobhan Banks:** Validation, Writing – review & editing. **Jillian Dorrian:** Methodology, Validation, Writing – review & editing, Visualization

Declaration of competing interest

None.

Data availability

The regulations I have used are publicly available.

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