Pilot In-Flight Sleep During Long-Range and Ultra-Long Range Commercial Airline Flights

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INTRODUCTION: In commercial aviation, pilot fatigue is a major threat to safety. One key fatigue mitigation strategy on long-range (LR; 8–16 h) and ultra-long range (ULR; 16+ h on at least 10% of trips) routes is allotting in-flight rest breaks for the pilots. Since sleep is a strong predictor of performance, it is important to quantify total in-flight sleep (TIFS) and determine rest scheme schedules that optimize sleep opportunity and subsequent performance. Here we quantify in-flight sleep and characterize rest schemes by type and efficiency.

METHODS: Between 2015 and 2019, we collected data on in-flight sleep on 3 LR and 5 ULR routes totaling 231 pilots flying over 1200 flight duty periods. Data were collected using a combination of actigraphy and logbooks.

RESULTS: Over all combinations of flight direction, crew and LR vs. ULR, average TIFS ranged from 3.4 h to 5.2 h with some ULR pilots getting over 8 h. Most crews made use of simple two- or three-break rest schemes and the complex four-break rest schemes were used almost exclusively on the three longest ULR routes. The complex schemes were less efficient than simple schemes, although this effect was small. Complex schemes resulted in no more TIFS compared to simple schemes on the same routes.

DISCUSSION: Overall, we find that crews are getting more sleep on these routes than previously reported on similar routes. Most crews use simple rest schemes and these simple schemes are more efficient than complex schemes.

KEYWORDS: aviation, rest scheme, total in-flight sleep, efficiency, aircrew.

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Commercial aviation operations require 24-h activities that include night work, long duty days, irregular work schedules, and multiple time zone changes. Since these conditions can lead to fatigue and, consequently, decrements in performance resulting in a reduction of safety, it is important to develop strategies to manage the risk brought about by fatigue.[6,17] One strategy used in the commercial aviation industry is to allow pilots to have an opportunity for sleep during the flight. Long-range (LR; durations between 8 and 16 h) and ultra-long range (ULR; durations longer than 16 h on at least 10% of the trips) flights require a three- or four-pilot crew with one or two crewmembers designated as the "flying" crew, and one or two crewmembers designated as the "relief" crew. The pilots in the "flying" crew operate the aircraft during the two critical phases of flight: at the start of the flight, from leaving the gate to the top of climb, and at the end of the flight, from the top of descent to returning to the gate. The relief pilot(s) operate the aircraft between top of climb and top of descent, during cruise. This allows the landing pilot in the "flying" crew to have an in-flight sleep opportunity of at least 2 h in the second half of the flight duty period as mandated by Federal Aviation Administration regulations (FAR part 117.17).[8]

Even though pilots are allowed in-flight sleep opportunities, there are a number of factors that determine if and how an opportunity for sleep is successfully converted into beneficial sleep. For example, opportunities for in-flight sleep are most successful when they line up with the times the pilot is naturally primed for sleep.[2,18] Sleep timing is generally thought to be governed by both homeostatic (a measurement of time awake) and

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circadian factors,[1,4] The circadian nature of sleep is one of the factors that makes it relatively easy to fall asleep at habitual bedtime, but difficult to sleep at other times of day, like during a "wake maintenance zone" a few hours before habitual bedtime.[5,15,23] Also, sleep that occurs at a time other than the biological night (circadian phase) tends to result in poorer sleep quality (i.e., less deep sleep and longer sleep latency).[5,13] Since pilots are frequently required to sleep at times that are not ideal for their circadian clock,[3,9] the circadian nature of sleep presents a challenge for pilots.

Not only does the timing of sleep during flights make it difficult to get good quality sleep, but other factors like noise and turbulence contribute to poorer sleep quality in flight than on the ground.[21] Therefore, it is important that crews get the best quality sleep and the largest amount of sleep possible during flights. Using wrist-based actigraphy and/or self-report measures like surveys, researchers can measure or estimate in-flight sleep amounts during flights at a level that is comparable to the gold standard of measuring sleep: polysomnography.[20] Previous studies have reported between 1 and 4 h of total in-flight sleep on LR[11,25] and/or ULR flights,[10,12,21] depending on flight duration. Although there is a decent amount of literature on in-flight rest on LR and ULR routes, most of the work on in-flight rest schemes specifically was done by only a couple of research groups, and apart from these groups, there is very little published data on in-flight rest scheme use on LR and ULR commercial airline flights. Therefore, our study was developed to expand on the current literature base. The purposes of this study were to determine how much in-flight sleep crews are getting on four-pilot LR and ULR flights, determine which types of rest schemes crews are using, and determine which rest schemes are the most efficient.

METHODS

Subjects

A total of 235 U.S. commercial airline pilots supplied data to the study (of those pilots that provided demographic data, 91% were men). The average age of pilots in the study was 52 (range: 36–64). Some of the participating pilots flew more than one route and some flew the same route multiple times, which resulted in a total of 1203 flight duty periods. This study included a total of three LR and five ULR routes. Data was collected from June 19, 2015, to Sept. 18, 2019.

The study was approved by the Washington State University Institutional Review Board. Participants were recruited from a population of pilots flying the Boeing 787 fleet and operating international flights based in the United States. Each Boeing 787 is equipped with a Class 1 Rest Facility, which is defined as an area that is separate from both the flight deck and passenger cabin that: 1) contains a bunk or other sleeping surface; 2) allows for a flat sleeping position; 3) is temperature controlled; 4) allows the flight crewmember to control light; and 5) provides isolation from noise and disturbance. All pilots on the eight routes studied were eligible to participate. Advertising was distributed via e-mail to potential participants. Prior to participating, interested pilots contacted the Occupational Sleep Medicine Group at Washington State University for study information and signed an Institutional Review Board-approved consent form. All individual data remained confidential and de-identified.

Procedure

The studied routes included flights from San Francisco (SFO) and Los Angeles (LAX) to Singapore (SIN); SFO and LAX to Sydney, Australia (SYD); LAX to Melbourne, Australia (MEL); LAX to Shanghai, China (PVG); SFO to PVG; SFO to Chengdu, China (CTU); and Houston (IAH) to SYD. Flights from SFO and LAX to SIN were combined in our analysis and presented as California to SIN (CAL-SIN). Flights from SFO and LAX to SYD were combined in our analysis and presented as California to SYD (CAL-SYD) as well. LAX and SFO can be combined as CAL since flights studied from LAX and SFO are westbound flights, have very similar flight duty periods and departure times, and are both based on the west coast of the United States. Additionally, a second SFO-SIN route with a different departure time was studied, which is presented here as SFO-SIN Early Departure (SFO-SIN ED). SFO-CTU, SFO-PVG, LAX-PVG routes are classified as LR while CAL-SYD, IAH-SYD, CAL-SIN, LAX-MEL, and SFO-SIN ED routes are classified as ULR.

To record sleep/wake history, participants received an Actigraph device (Philips Respironics, Bend, OR, USA; Models: Actiwatch Spectrum and Spectrum Plus), which reliably monitors human rest/activity cycles and quantifies sleep. A self-report sleep logbook was used to verify the actigraphy data. Actigraphs are designed to record a digitally integrated measure of gross motor activity that can be used to visualize rest-activity patterns or to quantify physical activity or sleep,[19] and has been validated compared to polysomnography.[7,14,16] All data were collected using a 1-min epoch length and a medium wake threshold (40 activity counts per epoch). The sleep interval detection algorithm was used for sleep onset (10 immobile minutes) and sleep end (10 immobile minutes). All times were configured to Coordinated Universal Time. Actigraph data were imported using Philips Actiware 6 software and then cleaned by comparing the actigraphy data to self-reported sleep/wake times, via logbooks and event markers, to ensure the algorithm correctly captured all sleep periods. The data were then imported, processed, analyzed, and visualized using the statistical programming language R. Sleep efficiency was measured as total in-flight sleep (TIFS) divided by total break time.

Eight different types of rest breaks were distinguished (**Fig. 1**). Each pilot's rest scheme was classified as one of these eight using a custom algorithm written in R and then confirmed by visual inspection. The eight rest schemes are as follows: "First": one crew takes one long break in the first half of the flight, allowing the other crew to have one long break in the second half of the flight; "Second": one crew takes one long break in the second half of the flight, allowing the other crew to have one long break in the first half of the flight; "Middle": one crew takes one long break in the

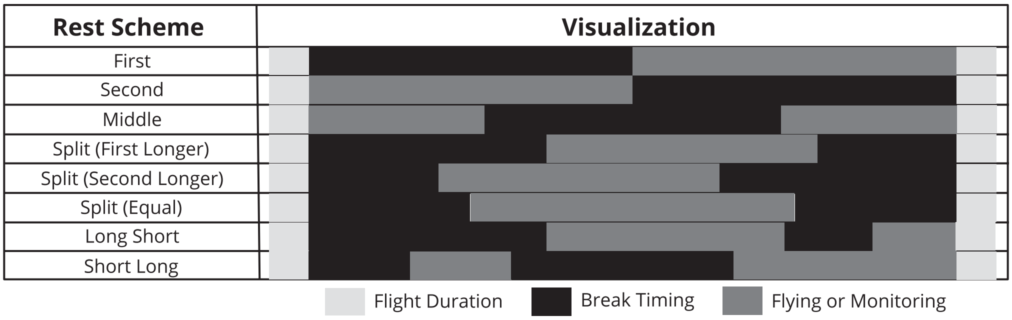

Fig. 1. Visual representation of the eight rest schemes.

middle of the flight, allowing the other crew to have two breaks, one before and one after this break; "Split (First Longer)": one crew takes two breaks, the first one longer than the second, allowing the other crew to have one break in between; "Split (Second Longer)": one crew takes two breaks, the second one longer than the first, allowing the other crew to have one break in between; "Split (Equal)": one crew takes two breaks of equal length, allowing the other crew to have one break in between; "Long Short": each crew takes two breaks and the first break is longer than the second; "Short Long": each crew takes two breaks and the second break is longer than the first.

RESULTS

Table I summarizes the departure times, arrival times, flight duration, flight duty duration, and layover duration for all studied flights. All outbound flights were westbound and all inbound flights were eastbound. The IAH-SYD, CAL-SIN, SFO-CTU, and SFO-SIN ED trips all had a scheduled layover of 48 h (not reducible to below 44 h). The CAL-SYD, LAX-MEL, LAX-PVG, and SFO-PVG trips had a scheduled layover of 24 h (not reducible to below 18 h). All scheduled layover lengths are the minimum required length and are based on Federal Aviation Regulations 14 CFR 117.3.

Across all LR routes for both crews and both outbound and inbound directions, the minimum average TIFS was 3.25 h (SFO-PVG Relief Crew inbound) and the maximum average TIFS was 4.70 h (SFO-CTU Flying Crew outbound). Across all ULR routes for both crews and both directions, the minimum average TIFS was 3.50 h (CAL-SYD Relief Crew inbound) and the maximum average TIFS was 5.90 h (IAH-SYD Relief Crew outbound). Individual TIFS values ranged from 0.28 h to 5.92 h for LR routes and 0.17 h to 8.07 h for ULR routes (separated by specific crew type) (See **Fig. 2**).

On 94% of LR flights and 65% of ULR flights, flying crews used the Second break scheme (average LR TIFS = 4.00 h; average ULR TIFS = 4.89 h), while relief crews took the First break (average LR TIFS = 3.46 h; average ULR TIFS = 4.50 h). No pilots on LR routes made use of complex four-break rest schemes (Split, Long Short, or Short Long). Of the ULR routes, except for two CAL-SYD relief crew flights, only pilots on the three longest ULR routes (IAH-SYD, CAL-SIN, SFO-SIN ED) used four-break rest schemes.

Table I. Departure Times, Arrival Times, Flight Durations, Duty Durations and Layover Durations for Each Route Studied.

DIRECTION & ROUTE (*N*)	DEPARTURE TIME MEAN (UTC)	ARRIVAL TIME MEAN (UTC)	FLIGHT DURATION (MEAN HOURS ± SD)	DUTY DURATION (MEAN HOURS ± SD)	LAYOVER DURATION (MEAN HOURS ± SD)
Outbound					
CAL-SYD (165)	06:22	21:11	14.8 ± 0.9	16.6 ± 0.6	27.1 ± 5.4
IAH-SYD (69)	03:11	20:38	17.5 ± 0.5	19.3 ± 0.5	55.6 ± 15.5
LAX-MEL (73)	06:09	22:00	15.9 ± 0.5	17.1 ± 2.8	25.3 ± 4.9
CAL-SIN (164)	06:06	23:01	17.0 ± 0.7	18.7 ± 0.9	49.9 ± 6.3
SFO-SIN ED (49)	18:46	11:54	17.1 ± 0.6	19.0 ± 0.7	48.7 ± 3.5
SFO-CTU (41)	22:11	12:31	14.0 ± 0.4	16.0 ± 1.2	62.3 ± 15.7
LAX-PVG (38)	20:29	10:04	13.6 ± 0.5	15.3 ± 0.6	25.5 ± 4.0
SFO-PVG (28)	22:12	11:16	13.1 ± 0.3	14.7 ± 0.5	36.7 ± 7.5
Inbound					
CAL-SYD (161)	00:43	14:13	13.5 ± 0.4	15.0 ± 0.5	
IAH-SYD (69)	23:56	15:28	15.5 ± 0.4	17.0 ± 0.5	
LAX-MEL (72)	00:00	14:08	14.1 ± 0.4	15.9 ± 0.7	
CAL-SIN (164)	01:41	16:42	15.0 ± 0.6	16.6 ± 0.7	
SFO-SIN ED (49)	13:45	04:18	14.5 ± 0.5	16.2 ± 0.6	
SFO-CTU (41)	02:19	15:02	12.7 ± 0.4	14.3 ± 0.9	
LAX-PVG (33)	12:28	23:50	11.3 ± 1.2	12.9 ± 0.7	
SFO-PVG (28)	06:15	17:08	10.8 ± 0.5	12.3 ± 0.6	

UTC: Coordinated Universal Time; CAL-SYD: California, USA, to Sydney, Australia; IAH-SYD: Houston, TX, USA, to Sydney, Australia; LAX-MEL: Los Angeles, CA, USA, to Melbourne, Australia; CAL-SIN: California, USA, to Singapore; SFO-SIN ED: San Francisco, CA, USA, to Singapore early departure; SFO-CTU: San Francisco, CA, USA, to Chengdu, China; LAX-PVG: Los Angeles, CA, USA, to Shanghai, China; SFO-PVG: San Francisco, CA, USA, to Shanghai, China.

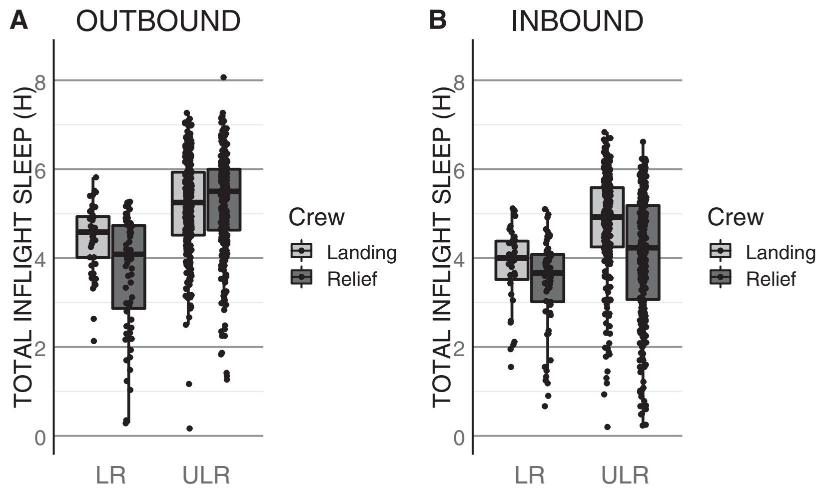

Fig. 2. Total in-flight sleep (in hours) based on crew and direction. Averages are as follows: 4.44 h (OB Landing LR), 3.72 h (OB Relief LR), 5.16 h (OB Landing ULR), 5.23 h. (OB Relief ULR), 3.80 h (IB Landing LR), 3.42 h (IB Relief LR), 4.77 h (IB Landing ULR), and 4.02 h (IB Relief ULR). OB = outbound; LR = long-range; ULR = ultra-long range; IB = inbound. The lower and upper hinges of each box correspond to the 25th and 75th percentiles, respectively. The horizontal line in the boxes is the median. The upper whisker extends from the hinge to the largest value no further than 1.5*IQR from the hinge (IQR = interquartile range). The lower whisker extends from the hinge to the smallest value at most 1.5*IQR of the hinge.

We calculated sleep efficiency, the percentage of the total break time spent sleeping, for each of the eight rest schemes. Sleep efficiencies by rest scheme: First, 67.5% ($N = 433$); Second, 76.5% ($N = 395$); Middle, 74.6% ($N = 132$); Split first, 71.6% ($N = 140$); Split second, 52.8% ($N = 3$); Split equal, 62.1% ($N = 2$); Long Short, 68.7% ($N = 36$); and Short Long, 62.6% ($N = 30$). Grouping by simple (two- or three-break) vs. complex (four-break) rest schemes, the average efficiencies are as follows: simple, 72.0% ($N = 1105$); and complex, 65.9% ($N = 66$). This difference was statistically significant using a two-sided Welch two sample t-test ($t = 2.86$, $P = 0.005$), although the effect size was small (Hedges' g = 0.26). Comparing the efficiency between two-break, three-break, and four-break rest schemes using a one-way ANOVA did not show any statistically significant differences. Performing multiple t-tests (two-break vs. three-break, two-break vs. four-break, three-break vs. four-break) using a Bonferonni correction did not reveal any significant differences. Comparing TIFS between four-break rest schemes and two- or three-break schemes on the same routes revealed that there was no statistically significant difference in TIFS between four-break schemes and simpler schemes (two-sided t-test; $P = 0.2$). **Table II** shows sleep efficiency broken down by crew and flight direction.

Table II. Sleep Efficiency of Each Rest Scheme, Separated Out by Crew and Direction.

	LANDING		RELIEF	
	OUTBOUND	INBOUND	OUTBOUND	INBOUND
First	62% ($N = 4$)	75% ($N = 5$)	71% ($N = 146$)	65% ($N = 278$)
Second	73% ($N = 122$)	78% ($N = 262$)	77% ($N = 9$)	28% ($N = 2$)
Middle	76% ($N = 123$)	60% ($N = 7$)	68% ($N = 2$)	
Split (First Longer)	68% ($N = 3$)		73% ($N = 121$)	64% ($N = 16$)
Split (Second Longer)			55% ($N = 2$)	49% ($N = 1$)
Split (Equal)			42% ($N = 1$)	82% ($N = 1$)
Long Short	60% ($N = 15$)	77% ($N = 1$)	75% ($N = 18$)	69% ($N = 2$)
Short Long	70% ($N = 10$)	60% ($N = 2$)	55% ($N = 12$)	67% ($N = 6$)

Empty locations indicate rest schemes that were not used by that crew+direction combination.

Flying Crew

Results for flying crews are shown in **Table III** (outbound direction) and **Table IV** (inbound direction). On seven out of the eight routes the outbound flying crew most frequently followed a Second or Middle schedule. The one exception was SFO-SIN ED, which followed a Short Long schedule most often (Table III). Across all LR routes, flying crews on the outbound portion averaged between 4.22 and 4.70 h of sleep, while crews on the ULR routes averaged between 4.8 and 5.57 h of sleep during the flight duty period. Flight duration averages were between 13 and 18 h with the shortest and longest individual flight durations being 12.68 h and 19.25 h, respectively.

The Second break rest scheme was the most commonly used for flying crews on inbound flights of each route (Table IV). Split schedules were used very infrequently (on IAH-SYD, one crew used Long Short and two crews used Short Long). First break rest schemes were only used on the LAX-PVG route, with only 28% of LAX-PVG pilots using this scheme. Across all inbound LR routes, landing crews averaged between 3.45 and 4.30 h of sleep, while landing crews on ULR routes averaged between 3.75 and 5.3 h of sleep during the flight duty period. Inbound flight durations were shorter than the outbound portions, averaging between 10 and 16 h depending on the route. The shortest individual inbound flight was an LAX-PVG flight (10 h) and the longest individual inbound flight durations were approximately 16.5 h (IAH-SYD and CAL-SIN).

Flying crews across all routes, both outbound and inbound, chose a Second break rest scheme the most frequently (Tables III and IV). Of the flying crews, 69% chose the Second break rest scheme.

Table III. Flying Crew Outbound.

ROUTE	*N*	FIRST	SECOND	MIDDLE	SPLIT (FIRST LONGER)	SPLIT (SECOND LONGER)	SPLIT (EQUAL)	LONG SHORT	SHORT LONG	TIFS (h) MEAN (MIN–MAX)	FLIGHT DURATION (h) MEAN (MIN–MAX)
CAL-SYD (ULR)	59	0.0	59.3	40.7	0.0	0.0	0.0	0.0	0.0	4.80 (3.10 - 6.02)	14.85 (13.95 - 15.97)
IAH-SYD (ULR)	44	0.0	6.8	75.0	0.0	0.0	0.0	18.2	0.0	5.57 (3.17 - 7.03)	17.44 (15.97 - 19.25)
LAX-MEL (ULR)	36	11.1	80.6	8.3	0.0	0.0	0.0	0.0	0.0	4.83 (0.17 - 6.63)	15.86 (15.05 - 17.18)
CAL-SIN (ULR)	81	0.0	11.1	76.5	3.7	0.0	0.0	8.6	0.0	5.37 (2.50 - 7.27)	16.96 (15.65 - 18.43)
SFO-SIN ED (ULR)	19	0.0	26.3	10.5	0.0	0.0	0.0	10.5	52.6	5.15 (1.17-6.98)	17.31 (16.30-18.18)
SFO-CTU (LR)	18	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	4.70 (2.63 - 5.82)	13.95 (12.68 - 14.58)
LAX-PVG (LR)	18	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	4.27 (3.40 - 5.42)	13.57 (13.12 - 14.82)
SFO-PVG (LR)	7	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	4.22 (2.80 - 4.88)	13.09 (12.73 - 13.47)

ULR: ultra-long range; LR: long-range; CAL-SYD: California, USA, to Sydney, Australia; IAH-SYD: Houston, TX, USA, to Sydney, Australia; LAX-MEL: Los Angeles, CA, USA, to Melbourne, Australia; CAL-SIN: California, USA, to Singapore; SFO-SIN ED: San Francisco, CA, USA, to Singapore early departure; SFO-CTU: San Francisco, CA, USA, to Chengdu, China; LAX-PVG: Los Angeles, CA, USA, to Shanghai, China; SFO-PVG: San Francisco, CA, USA, to Shanghai, China.
Values shown in the columns labeled "First" through "Short Long" are the percentage of pilots (per route) who followed each rest scheme. Total in-flight sleep and average flight durations, with ranges, are also displayed.

Table IV. Flying Crew Inbound.

ROUTE	*N*	FIRST	SECOND	MIDDLE	SPLIT (FIRST LONGER)	SPLIT (SECOND LONGER)	SPLIT (EQUAL)	LONG SHORT	SHORT LONG	TIFS (h) MEAN (MIN–MAX)	FLIGHT DURATION (h) MEAN (MIN–MAX)
CAL-SYD (ULR)	60	0.0	98.3	1.7	0.0	0.0	0.0	0.0	0.0	4.52 (1.18–5.92)	13.58 (12.97–14.32)
IAH-SYD (ULR)	43	0.0	90.7	2.3	0.0	0.0	0.0	2.3	4.7	5.30 (2.32–6.70)	15.61 (14.40–16.48)
LAX-MEL (ULR)	35	0.0	97.1	2.9	0.0	0.0	0.0	0.0	0.0	4.45 (1.45–5.98)	14.11 (13.20–15.17)
CAL-SIN (ULR)	82	0.0	95.1	4.9	0.0	0.0	0.0	0.0	0.0	5.18 (1.98–6.83)	15.07 (13.42–16.53)
SFO-SIN ED (ULR)	19	0.0	94.7	5.3	0.0	0.0	0.0	0.0	0.0	3.75 (0.93–5.82)	14.51 (13.73–15.55)
SFO-CTU (LR)	19	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	4.30 (2.58–5.12)	12.65 (11.85–13.45)
LAX-PVG (LR)	18	27.8	72.2	0.0	0.0	0.0	0.0	0.0	0.0	3.50 (1.55–5.92)	11.44 (10.02–12.42)
SFO-PVG (LR)	7	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	3.45 (2.05–4.13)	10.94 (10.12–11.47)

ULR: ultra-long range; LR: long-range; CAL-SYD: California, USA, to Sydney, Australia; IAH-SYD: Houston, TX, USA, to Sydney, Australia; LAX-MEL: Los Angeles, CA, USA, to Melbourne, Australia; CAL-SIN: California, USA, to Singapore; SFO-SIN ED: San Francisco, CA, USA, to Singapore early departure; SFO-CTU: San Francisco, CA, USA, to Chengdu, China; LAX-PVG: Los Angeles, CA, USA, to Shanghai, China; SFO-PVG: San Francisco, CA, USA, to Shanghai, China.
Values shown in the columns labeled "First" through "Short Long" are the percentage of pilots (per route) who followed each rest scheme. Total in-flight sleep and average flight durations, with ranges, are also displayed.

Table V. Relief Crew Outbound.

ROUTE	*N*	FIRST	SECOND	MIDDLE	SPLIT (FIRST LONGER)	SPLIT (SECOND LONGER)	SPLIT (EQUAL)	LONG SHORT	SHORT LONG	TIFS (h) MEAN (MIN-MAX)	FLIGHT DURATION (h) MEAN (MIN-MAX)
CAL-SYD (ULR)	84	53.6	0.0	0.0	44.0	0.0	0.0	2.4	0.0	5.07 (1.35 - 6.23)	14.90 (13.85 - 15.95)
IAH-SYD (ULR)	25	20.0	0.0	0.0	64.0	0.0	0.0	16.0	0.0	5.90 (2.83 - 7.08)	17.53 (16.78 - 18.87)
LAX-MEL (ULR)	37	70.3	24.3	0.0	5.4	0.0	0.0	0.0	0.0	5.28 (2.98 - 7.20)	15.84 (14.83 - 17.93)
CAL-SIN (ULR)	82	8.5	0.0	2.4	75.6	1.2	1.2	11.0	0.0	5.70 (2.25 - 8.07)	16.95 (15.60 - 18.38)
SFO-SIN ED (ULR)	30	20.0	0.0	0.0	23.3	3.3	0.0	13.3	40.0	4.18 (1.27-6.57)	17.02 (15.97-17.88)
SFO-CTU (LR)	20	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.05 (1.03 - 5.27)	14.13 (13.47 - 14.77)
LAX-PVG (LR)	21	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.42 (0.28 - 5.22)	13.61 (12.40 - 14.27)
SFO-PVG (LR)	21	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.42 (0.35 - 4.73)	13.04 (12.45 - 13.57)

ULR: ultra-long range; LR: long-range; CAL-SYD: California, USA, to Sydney, Australia; IAH-SYD: Houston, TX, USA, to Sydney, Australia; LAX-MEL: Los Angeles, CA, USA, to Melbourne, Australia; CAL-SIN: California, USA, to Singapore; SFO-SIN ED: San Francisco, CA, USA, to Singapore early departure; SFO-CTU: San Francisco, CA, USA, to Chengdu, China; LAX-PVG: Los Angeles, CA, USA, to Shanghai, China; SFO-PVG: San Francisco, CA, USA, to Shanghai, China.
Values shown in the columns labeled "First" through "Short Long" are the percentage of pilots (per route) who followed each rest scheme. Total in-flight sleep and average flight durations, with ranges, are also displayed.

Table VI. Relief Crew Inbound.

ROUTE	*N*	FIRST	SECOND	MIDDLE	SPLIT (FIRST LONGER)	SPLIT (SECOND LONGER)	SPLIT (EQUAL)	LONG SHORT	SHORT LONG	TIFS (h) MEAN (MIN–MAX)	FLIGHT DURATION (h) MEAN (MIN–MAX)
CAL-SYD (ULR)	83	95.2	0.0	0.0	2.4	0.0	0.0	0.0	2.4	3.50 (0.50–5.52)	13.50 (12.58–14.67)
IAH-SYD (ULR)	26	69.2	0.0	0.0	15.4	0.0	3.8	3.8	7.7	4.45 (0.23–6.23)	15.41 (14.92–16.15)
LAX-MEL (ULR)	38	94.7	0.0	0.0	2.6	2.6	0.0	0.0	0.0	3.68 (0.20–6.03)	14.14 (13.30–15.32)
CAL-SIN (ULR)	81	96.3	0.0	0.0	2.5	0.0	0.0	0.0	1.2	4.47 (0.60–6.18)	14.91 (13.40–16.38)
SFO-SIN ED (ULR)	30	70.0	0.0	0.0	23.3	0.0	0.0	3.3	3.3	4.58 (1.70–6.62)	14.57 (13.17–15.82)
SFO-CTU (LR)	19	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.58 (0.90–5.10)	12.76 (12.08–13.73)
LAX-PVG (LR)	20	90.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.52 (1.25–4.40)	11.41 (10.00–12.42)
SFO-PVG (LR)	21	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.25 (1.18–4.17)	10.78 (9.48–11.75)

ULR: ultra-long range; LR: long-range; CAL-SYD: California, USA, to Sydney, Australia; IAH-SYD: Houston, TX, USA, to Sydney, Australia; LAX-MEL: Los Angeles, CA, USA, to Melbourne, Australia; CAL-SIN: California, USA, to Singapore; SFO-SIN ED: San Francisco, CA, USA, to Singapore early departure; SFO-CTU: San Francisco, CA, USA, to Chengdu, China; LAX-PVG: Los Angeles, CA, USA, to Shanghai, China; SFO-PVG: San Francisco, CA, USA, to Shanghai, China.
Values shown in the columns labeled "First" through "Short Long" are the percentage of pilots (per route) who followed each rest scheme. Total in-flight sleep and average flight durations, with ranges, are also displayed.

Relief Crew

For relief crews on the outbound portion of flights, the most preferred type of rest break scheme was First, which was used by most pilots on five of the eight routes (**Table V**). Relief crews on outbound flights for IAH-SYD and CAL-SIN most frequently followed a Split First schedule while relief crews on outbound flights on the SFO-SIN ED route most frequently followed a Short Long schedule. For outbound relief crews on LR routes, average sleep time per route ranged from 3.42 to 4.05 h, while outbound relief crews on ULR routes averaged between 4.18 and 5.9 h during the flight duty period. All relief crew pilots studied on all three LR routes opted for a First break rest scheme.

For the inbound portion, relief crews across all routes most frequently followed the First break rest scheme (**Table VI**). Inbound relief crews on LR routes averaged between 3.25 and 3.58 h of in-flight sleep, while inbound relief crews on ULR routes averaged between 3.50 and 4.58 h of in-flight sleep. Across outbound and inbound flights, 69% of the relief crew pilots followed the First break rest scheme.

DISCUSSION

Studying over 200 pilots flying 8 LR or ULR routes, we found LR flight crews are getting 3.7 h TIFS on average, and ULR flight crews are getting 4.7 h TIFS on average, with individual crews getting up to 8 h TIFS on some ULR flights. Most crews selected a simple rest scheme (First, Second, or Middle schemes). The four-break rest schemes (Long Short and Short Long) were not chosen very often (mainly only on IAH-SYD, CAL-SIN, and SFO-SIN ED). Furthermore, pilots who made use of a four-break rest scheme used breaks less efficiently for sleep compared to two- or three-break schemes, although this effect was small. Taken as a whole, our data show that flight crews on these LR and ULR flights are getting an average of 4.5 h of in-flight sleep, simple rest schemes are chosen much more frequently than complex rest schemes, and four-break rest schemes result in lower sleep efficiency than simpler schemes and are no better than simpler rest schemes in terms of TIFS.

A recent study by Gregory et al.[11] found pilots obtained approximately 1.5 h TIFS, compared to TIFS values reported here between 3.2 and 4.7 h. However, in the study conducted by Gregory et al., the average flight duty time was 10 h and crews were made up of three pilots. Here we report data from four-pilot crews flying LR flights that were generally longer (ranging from 10–14 h flight duration). These two differences likely explain the discrepancy of TIFS values.

Some previous studies quantified TIFS and sleep efficiency in LR and ULR flights of comparable length to those studied here, but did not compare different rest schemes.[12,21,22] For every combination of flight direction and crew, we report more TIFS than Gander and Signal[10] for both LR and ULR routes (see Fig. 2). Gander and Signal's[10] study reported TIFS values between 3.5 and 4.1 h on average for ULR routes (based on crew and direction) and between 3.1 and 3.3 h on average for

LR routes (based on crew and direction). These TIFS values were the basis for their recommendation to split breaks up into four-break rest schemes for the crews. The values of TIFS that we report here are also higher than those reported previously.[12,21,22] The study by Holmes and colleagues[12] studied one ULR route and reported outbound TIFS values averaging 2.6 h for both crews and inbound TIFS of 3.1 and 4.3 h based on crew. It should be noted in the Holmes et al.[12] study that they planned the four-break scheme and did not compare it to other break schemes, stating the purpose of this scheme was to reduce time-on-task effects and making it more likely that pilots could obtain some sleep if there was turbulence during one rest break.

Our findings counter the current literature and recommendations based on former studies because we found that pilots on our studied routes had much longer sleep durations than ~3 h, with one individual getting over 8 h. Additionally, the pilots in the study were able to obtain large amounts of sleep, even with the potentiality of turbulence, while reducing time spent prepping for and leaving their rest breaks. Also, we would argue that obtaining more sleep in flight (and likely in the 24-h period) and, therefore, reducing sleep pressure overall, is more likely to increase alertness than reducing time-on-task effects.

The study conducted by Signal et al.[21] reported 3.3 h of TIFS for one ULR route and a later study from the same group reported between 0.8 and 3.3 h.[22] In terms of sleep efficiency, two previous studies reported sleep efficiency values between 71 and 77% for a four-break rest scheme based on LR/ULR + direction + crew combination.[9,22] These values are slightly higher than what we calculate here for four-break schemes (65.9%), and, as noted previously, in Gander and Signal's[10] study, they did not compare four-break schemes to simpler ones. Additionally, Gander and Signal[10] used a slightly different definition of sleep efficiency, and this difference may have led to slightly higher efficiency values compared to what we show here. They defined sleep efficiency as the percentage of time spent trying to sleep that was actually scored as sleep, while we define it as the percentage of break time spent sleeping. Our definition may yield lower efficiency values since some of the break time may be needed for activities other than trying to sleep (e.g., walking to the rest facility). Further investigation by Signal and colleagues[21] reported sleep efficiencies similar to what we report here: 67.5% for a "First" scheme and 72.6% for a "Second" rest scheme (compared to 67.5% and 76.5%, respectively, in the current study). Compared to Signal's work, our results display the same efficiency for "First" rest schemes, slightly higher efficiency for "Second" rest schemes, and lower efficiency for four-break schemes. Therefore, the current literature on rest schemes in LR and ULR flights demonstrates pilots are sleeping on average between 2.5 and 4.5 h in flight, while our subjects are sleeping on average between 3.3 and 5.1 h per flight. We calculate similar sleep efficiency compared to previous studies for simple rest schemes, but lower efficiency in four-break schemes.

One of our purposes for studying rest schemes was to build scientifically based recommendations, compare them to what pilots are actually doing in flight, and then highlight routes where pilots may need more sleep education. Indeed, we developed recommendations for each of the studied routes. Although, since the recommendations were not always implemented at the initiation of a route (some routes have been flown for many years), we do not discuss adherence to the recommendations here.

The rest schemes that consist of four breaks (Long Short and Short Long; two breaks per crew) were mainly used on the SFO-SIN ED and IAH-SYD routes. These rest schemes can satisfy FAA regulations specified in FAR 117.17 for 2 consecutive hours of sleep opportunity available for the landing pilot in the second half of the flight duty period. However, sleep efficiency is lower for these four-break rest schemes compared to simple (two- or three-break) rest schemes. This may be because it takes considerable time for pilots to get organized in the bunk, wake up from the bunk, wait for sleep inertia to dissipate, then transition to duties on the flight deck. As a result, each extra break shortens the time that could otherwise be allocated for sleep. Therefore, our data indicate that break types involving more than three sleep periods are not the most efficient.

Since the routes used in this study varied substantially in duration, we compared sleep efficiency between rest schemes rather than simply the total amount of in-flight sleep. One of the results we present here, that four-break schemes are less efficient than simpler schemes, is partially at odds with a similar study from 2015, in which van den Berg and colleagues reported that simple two-break rest schemes resulted in significantly more in-flight sleep compared to one four-break rest scheme (using first and third breaks), but not another (using second and fourth breaks).[24] The discrepancy could be because van den Berg reported data from cabin crews rather than flight crews. Additionally, they collected data on only one route, whereas we compared four-break schemes to simpler schemes across eight routes.

While an advantage of the current study is that the data were collected in a real operational environment rather than a simulator, this approach also has its drawbacks, namely that we did not have a counterbalanced cross-over study design. In an ideal hypothetical situation, each pilot would have made use of each rest scheme at least once. If that were the case, we could then be certain that the difference in TIFS between schemes are not due to differences in the pilots who happened to use each rest scheme. Also, this would have made for a paired comparison for each scheme, allowing for stronger statistical inferences to be made. This type of study would be impractical in real world scenarios and unethical since not every rest scheme was appropriate for providing the most recuperative sleep on each route.

Further research should address the effectiveness of complex rest break schemes vs. simple rest break schemes based on safety performance indicators such as cognitive performance, fatigue, and sleepiness. Also, future research could assess how in-flight sleep timing, in reference to the circadian rhythm, affects safety performance indicators. The current study extends the published literature on commercial airline in-flight sleep and rest schemes. Our study counters findings from data on other commercial airlines, with key differences being that the pilots in our study averaged 4.7 h of TIFS on ULR routes, with individual pilots obtaining slightly over 8 h of TIFS. Therefore, our data demonstrate that pilots can obtain more in-flight sleep than was previously assumed based on the published literature. Turbulence did not appear to be a major factor that kept pilots from getting substantial amounts of in-flight sleep. Beyond this, we found sleep efficiency to be better for the simple rest schemes compared to the complex rest schemes. Replication studies are needed that potentially include some qualitative methods to assess why different research groups report different sleep efficiency and TIFS results. One speculative answer to this is that different airlines may have cultures that somehow act as a mediator between flight duty period, rest schemes, TIFS, and sleep efficiency. Collecting more data, and analyzing with these various factors in mind, will help researchers gain a broader understanding of the key factors that affect in-flight sleep and subsequent performance.

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