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The physiology of rapid time zone transitions – prediction of acclimatisation with a bio-mathematical model (SAFE)

4th November 2015

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Fatigue Risk Management Science Limited

Managing Occupational Alertness Makes Good Business Sense

Agenda

- Physiology changes after rapid time zone changes (Jet Lag)
- What is acclimatisation
- How long does it take to acclimatise?
- Aircrew and long haul flights
- It is all about minimising fatigue
- Background to a bio-mathematical model (SAFE)
- Examples of model predictions of acclimatisation
- Conclusions

What is Jet Lag ?

- A temporary disruption of physiological and psychological bodily rhythms (caused by high-speed travel across several time zones) resulting in fatigue, **difficulty in obtaining sufficient sleep** and other symptoms
- Drive for sleep and wakefulness and other daily rhythms are not synchronised with new environment
- Time zone adaptation or **acclimatisation** takes **several days** and depends on the direction of travel and number of time zones crossed as well as exposure to light and its influence on melatonin

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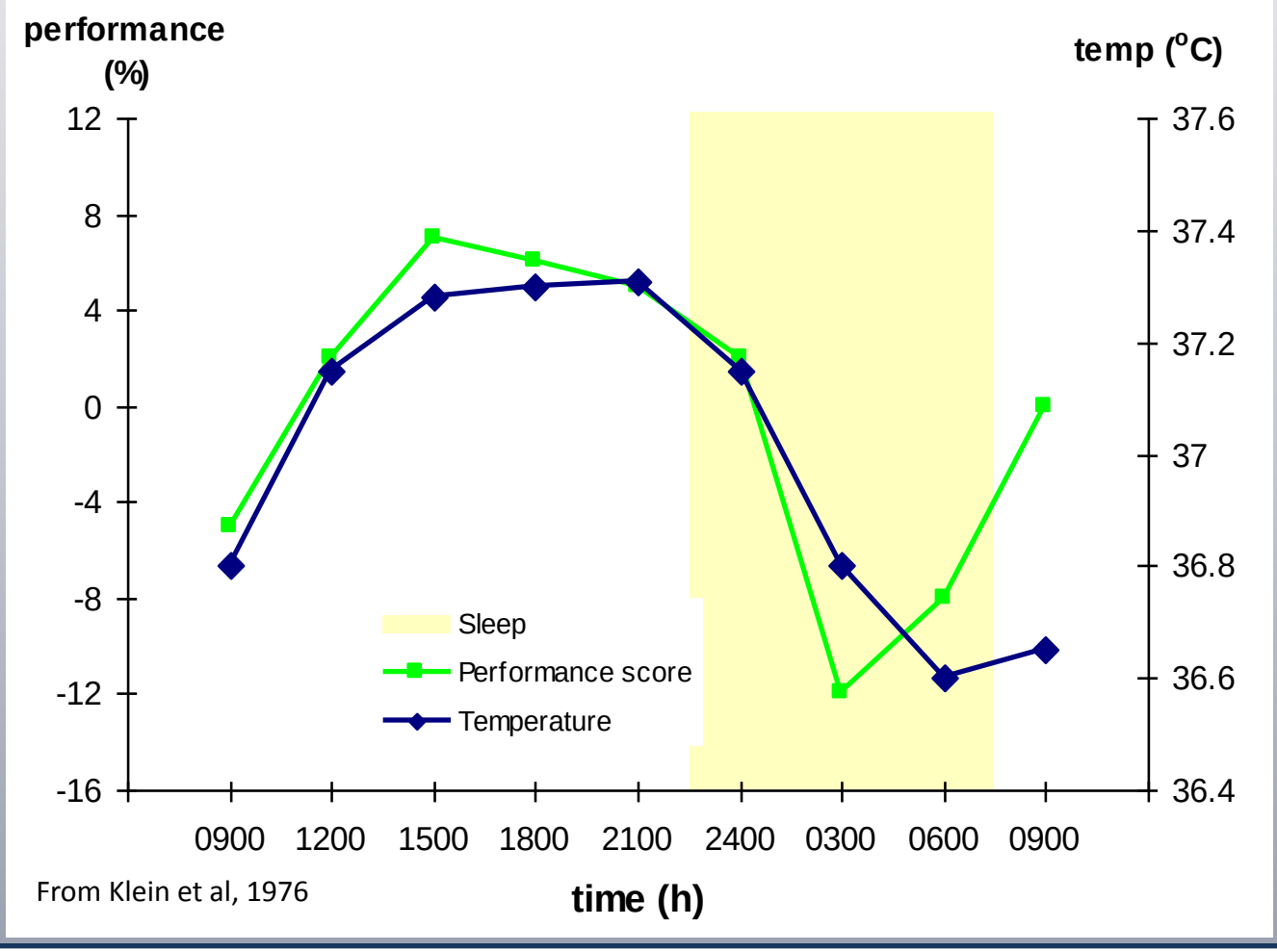
Circadian Rhythm of performance and core body temperature when acclimatised



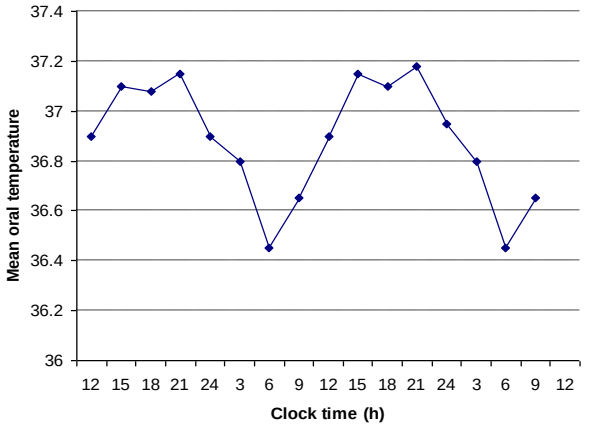
Sleep and relationship to circadian phase

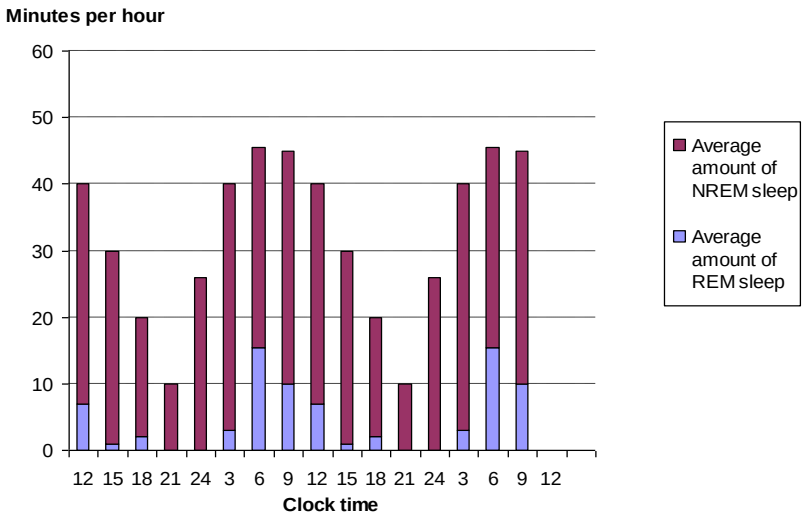
1. Ability to sleep varies with circadian phase

- Individuals trying to sleep at the crest of the circadian temperature curve are only able to sleep for a short time
- At the trough of the temperature cycle able to sleep for much longer

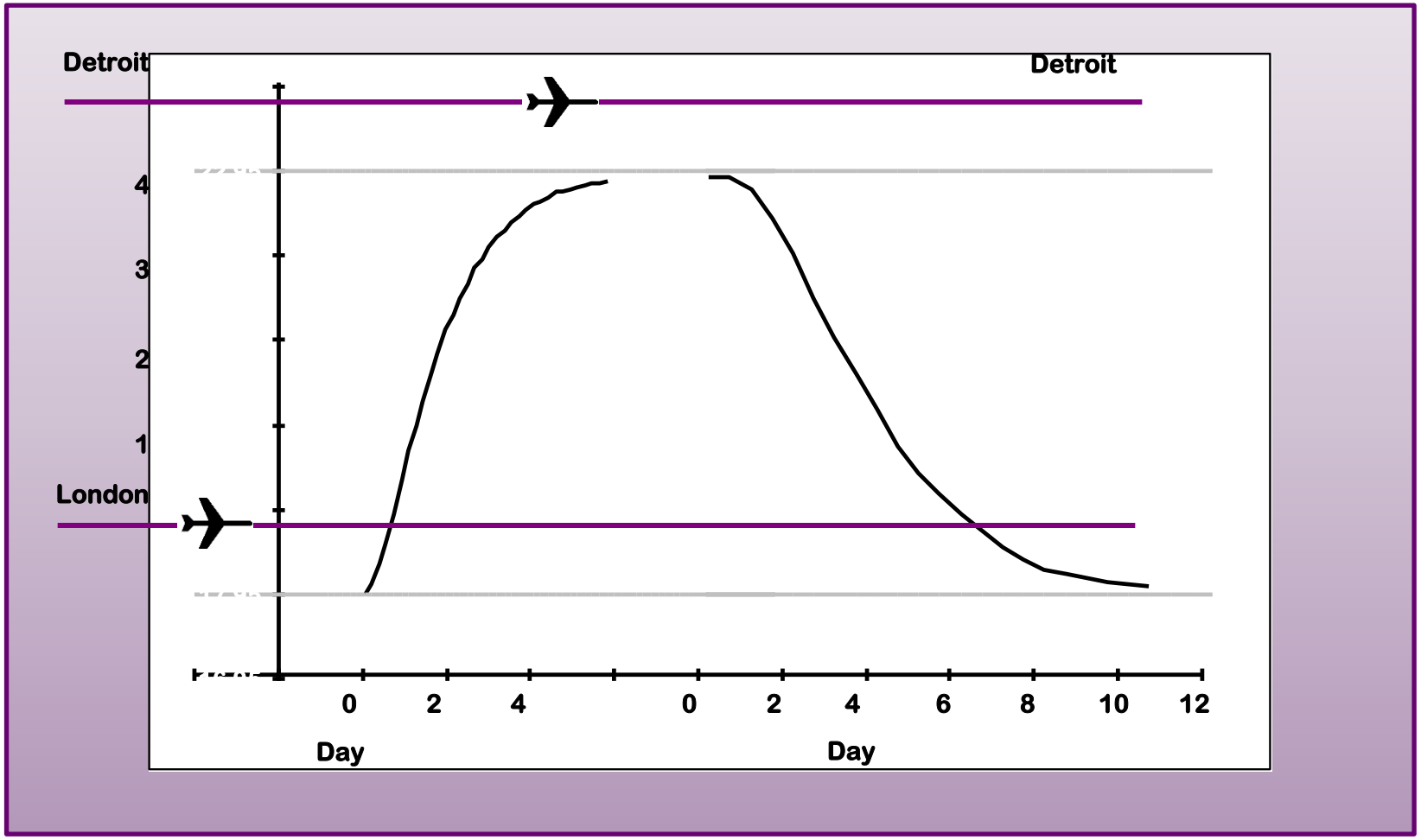
2. 'Forbidden zone' for sleep described by Lavie (1986)

- Period a couple of hours before habitual bed time
- Period of longest sleep latencies



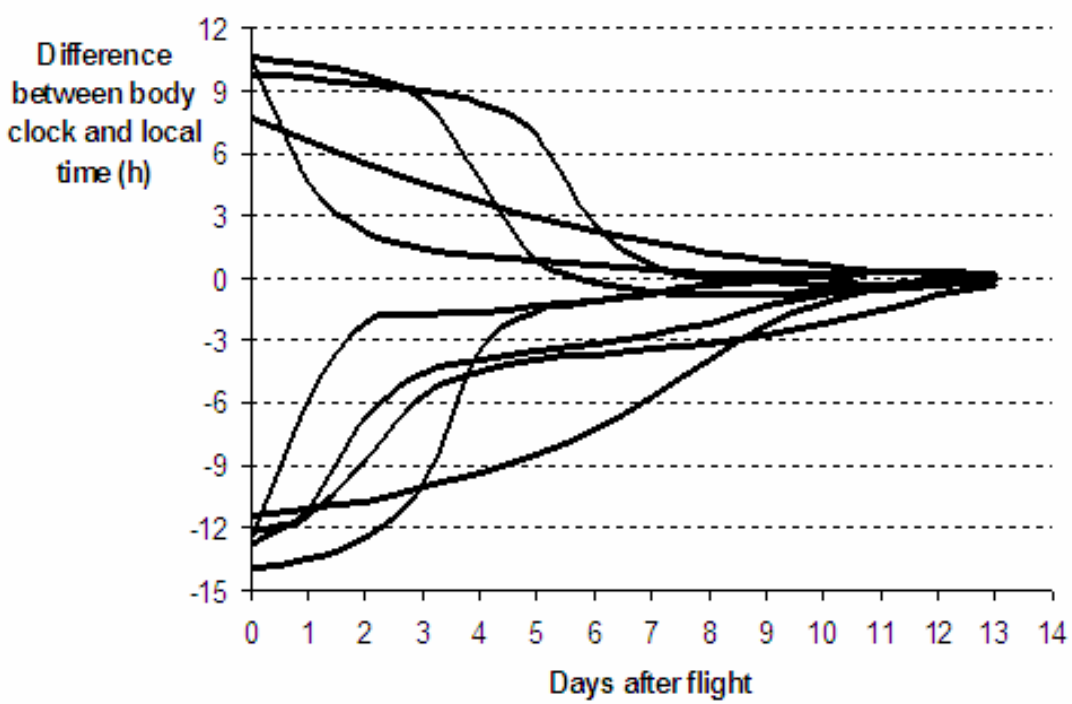


Adaptation of the circadian rhythm to 5-hour time zone transition



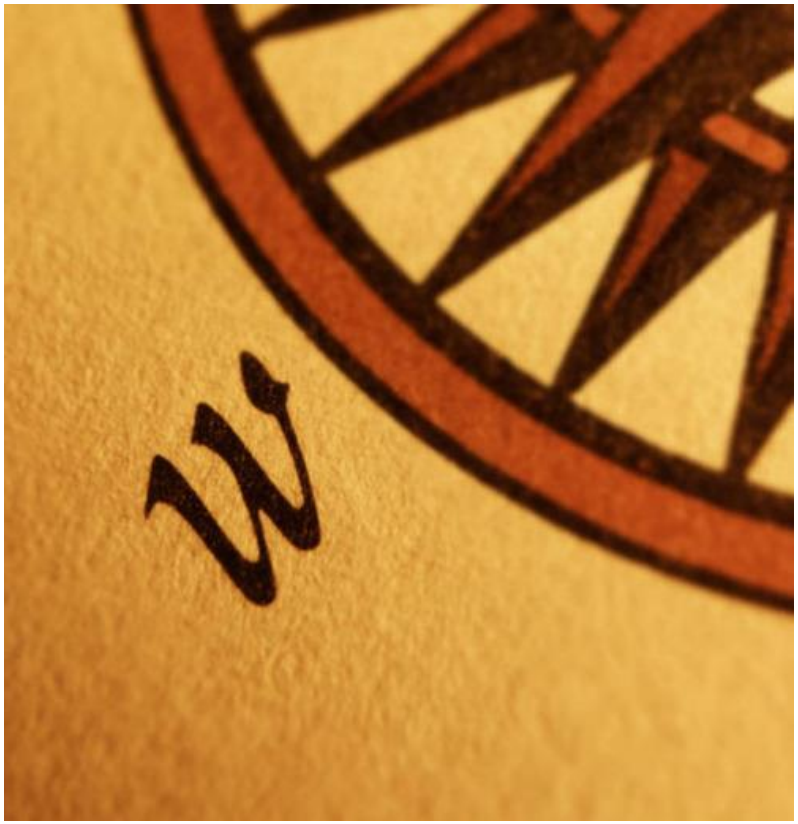
Adaptation of the circadian rhythm to a 10-hour eastward transition

- Pattern of adaptation varies considerably
  - some individuals took more than a week to adapt
- Even the direction of adaptation varied
- The amplitude of the rhythms was much reduced



Sleep after westward flights

- Sleep onset faster
- Second half of sleep period more disturbed
- First night after arrival SWS increases, REM sleep reduces
- On second and third nights the REM/NREM ratio increases
- By fourth night normal sleep pattern and alertness pattern is established
- Changes related to sleeping late in the time zone to which adapted



Sleep after eastward flight

- First night better sleep than baseline
- REM/NREM ratio reduced
- Second night longer sleep onset
- Reduced Slow Wave Sleep (SWS) on fourth night
- Fifth night total sleep time and sleep efficiency down
- Changes related to sleeping early in the time zone to which adapted

Main issues influencing alertness in long-haul operations

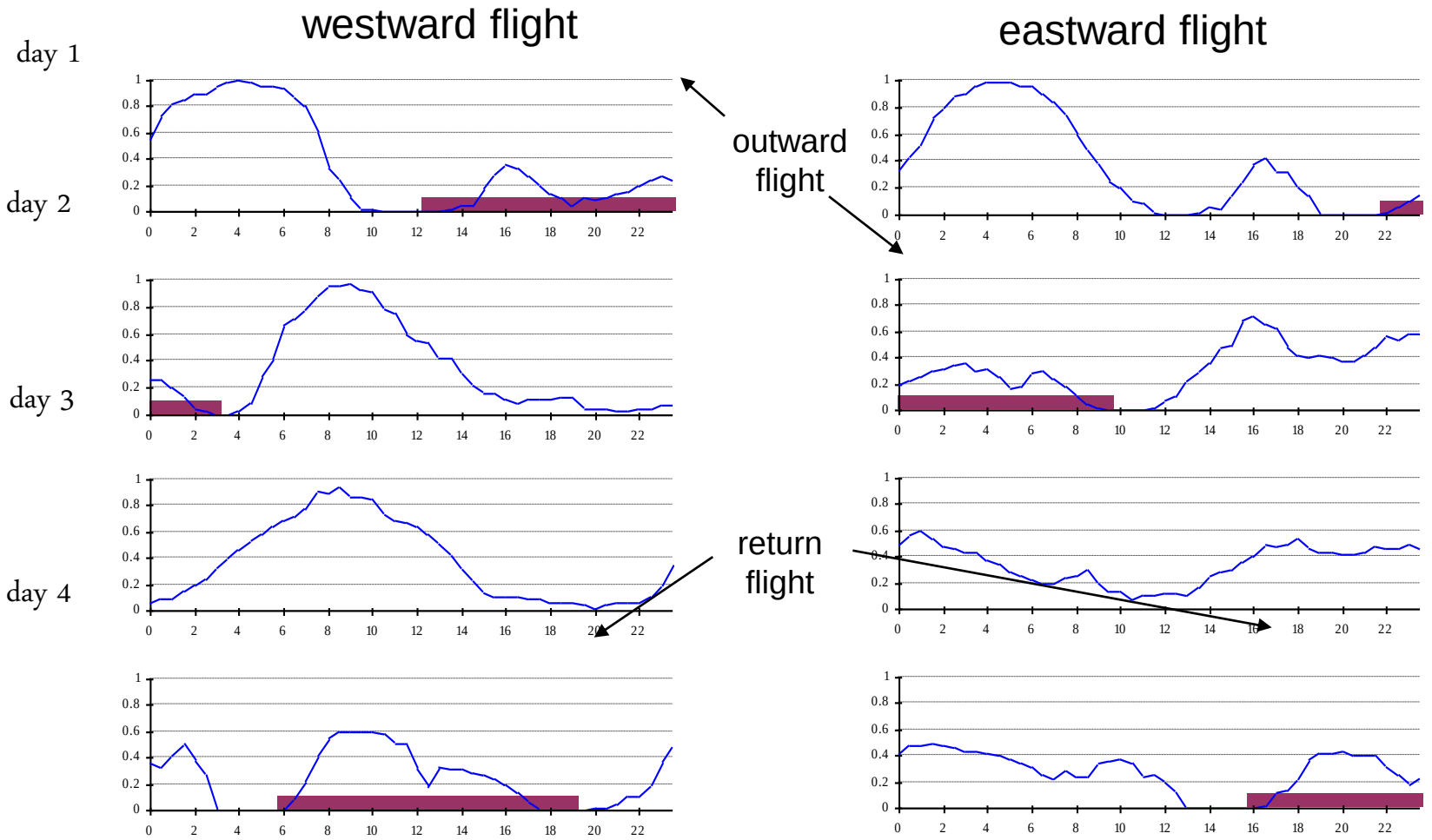
- Overnight flights mean operating in the **window of circadian low** (WOCL)
- After a time-zone transition, the body clock is temporarily **out of synchronisation** with the local environment
- Readjustment can take **several days**
- During this time, sleep may be disturbed and **alertness / performance may be badly affected**
- The problems tend to be more severe after an **eastward** than after a westward flight

- For aircrew there are advantages in **minimising the exposure** to the new time zone

Main issues (continued)

- Long duty periods
- Often a very low workload
- Risk of high levels of sleepiness
- Management of crew alertness in-flight
- The requirement for additional crew members (augmentation)
- The provision of in-flight rest facilities
- In particular, the maintenance of alertness during the critical period at the end of the flight
- Management of sleep during layover period

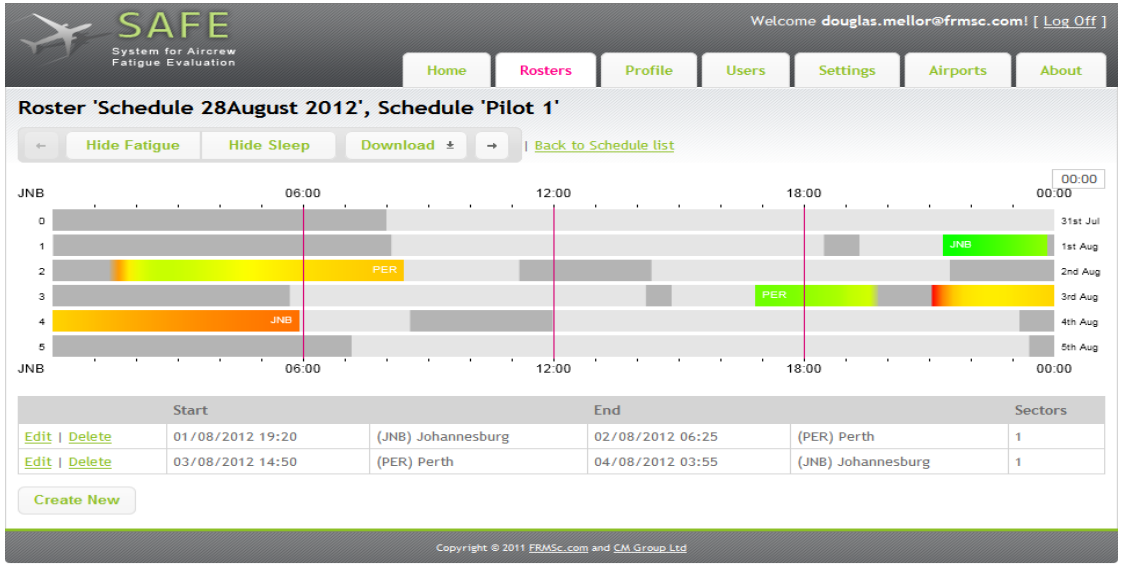
Sleep timing after westward and eastward flights



In-flight Rest

- Augmented crew
- Napping on board

Sleep Inertia must be avoided with in flight sleep



- Potential concern with cockpit napping or **in-flight sleep**
- To reduce the risk of sleep inertia after cockpit napping, the recommendation is to limit the time available for the nap to **40 minutes** (too short for most people to enter SWS)
- Benefits of in-flight sleep greatly **out-weigh the potential risks** associated with sleep inertia.

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3 Pilot Crew

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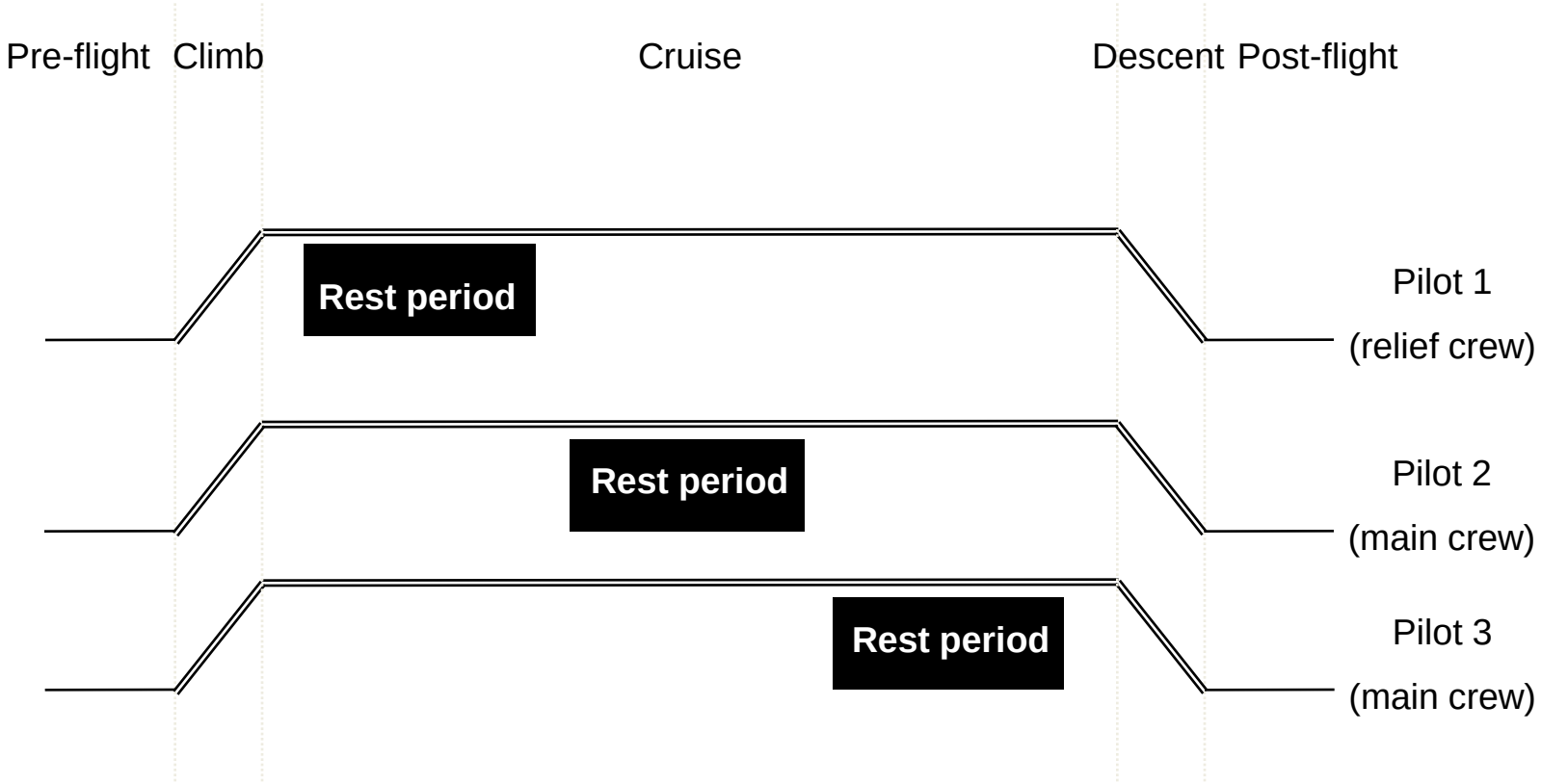
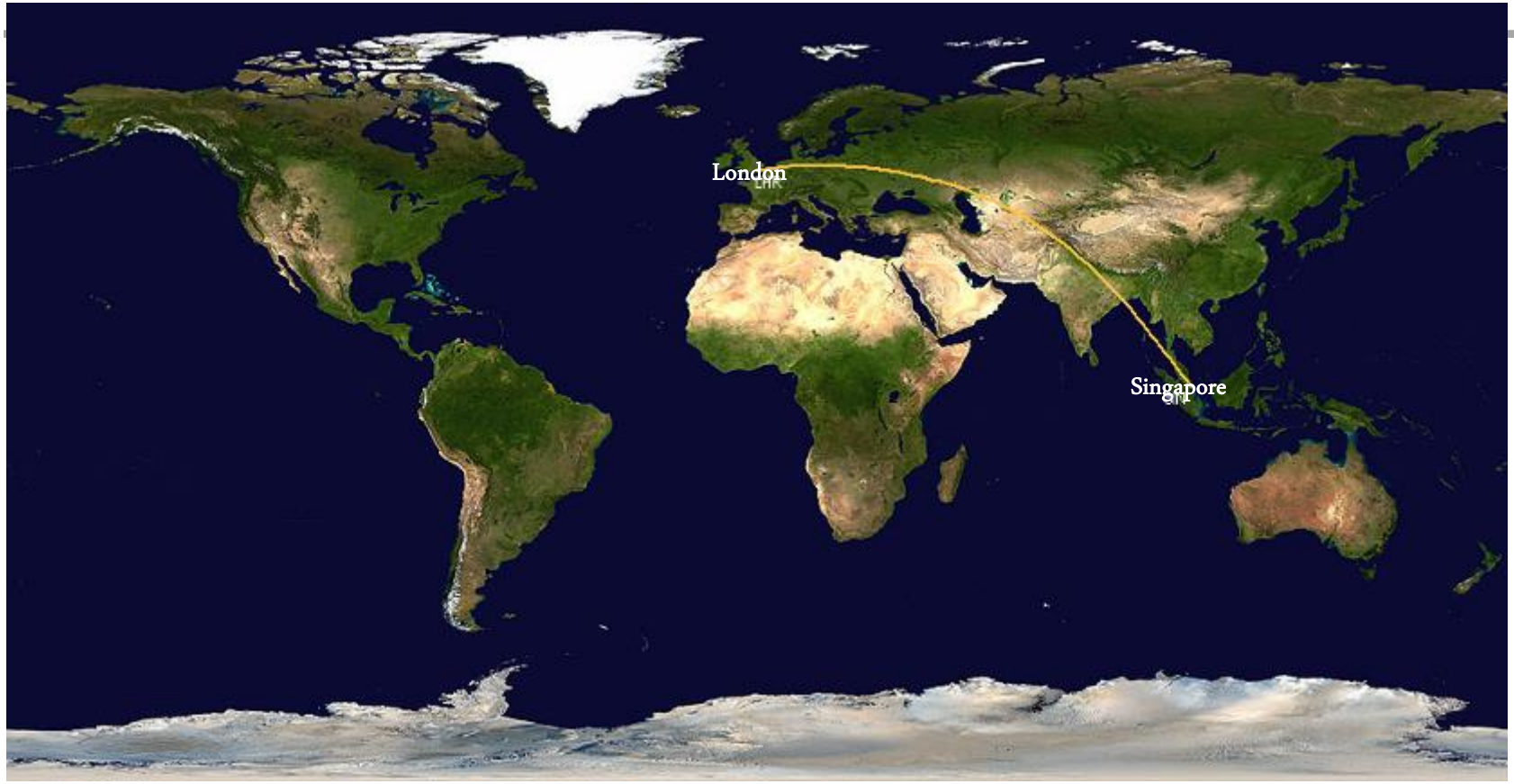
Organisation of in-flight rest periods



4 Pilot Crew



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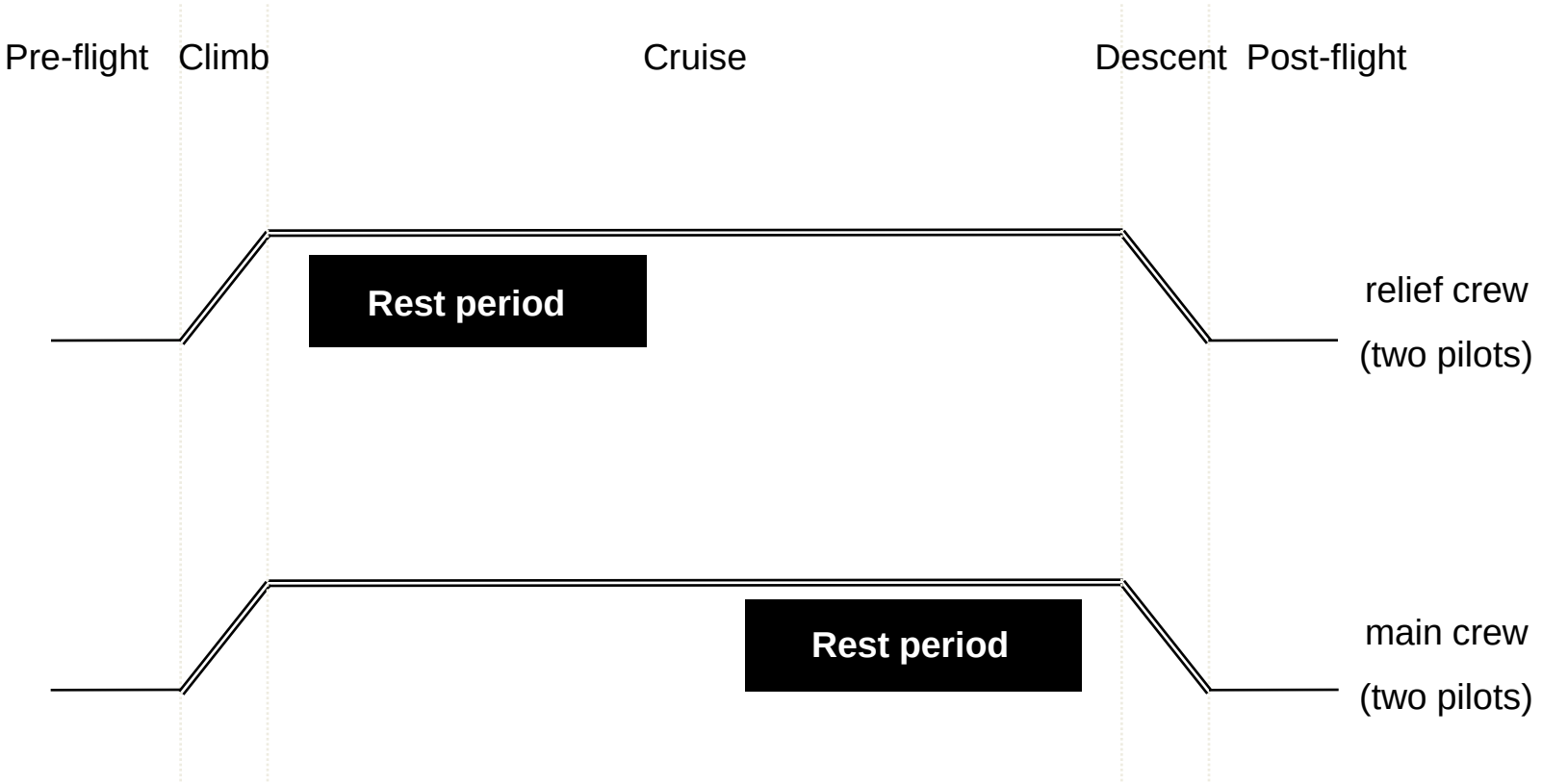
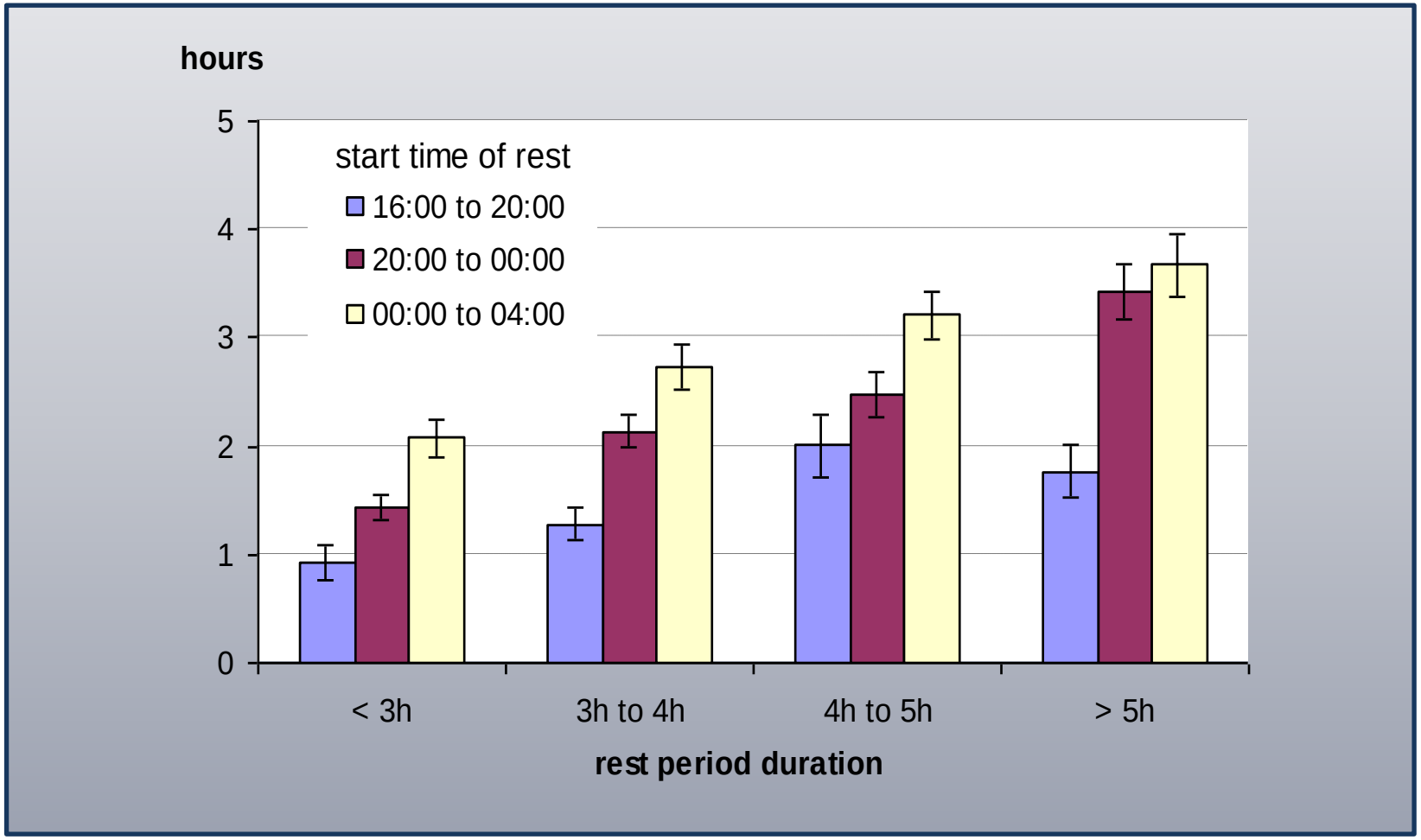
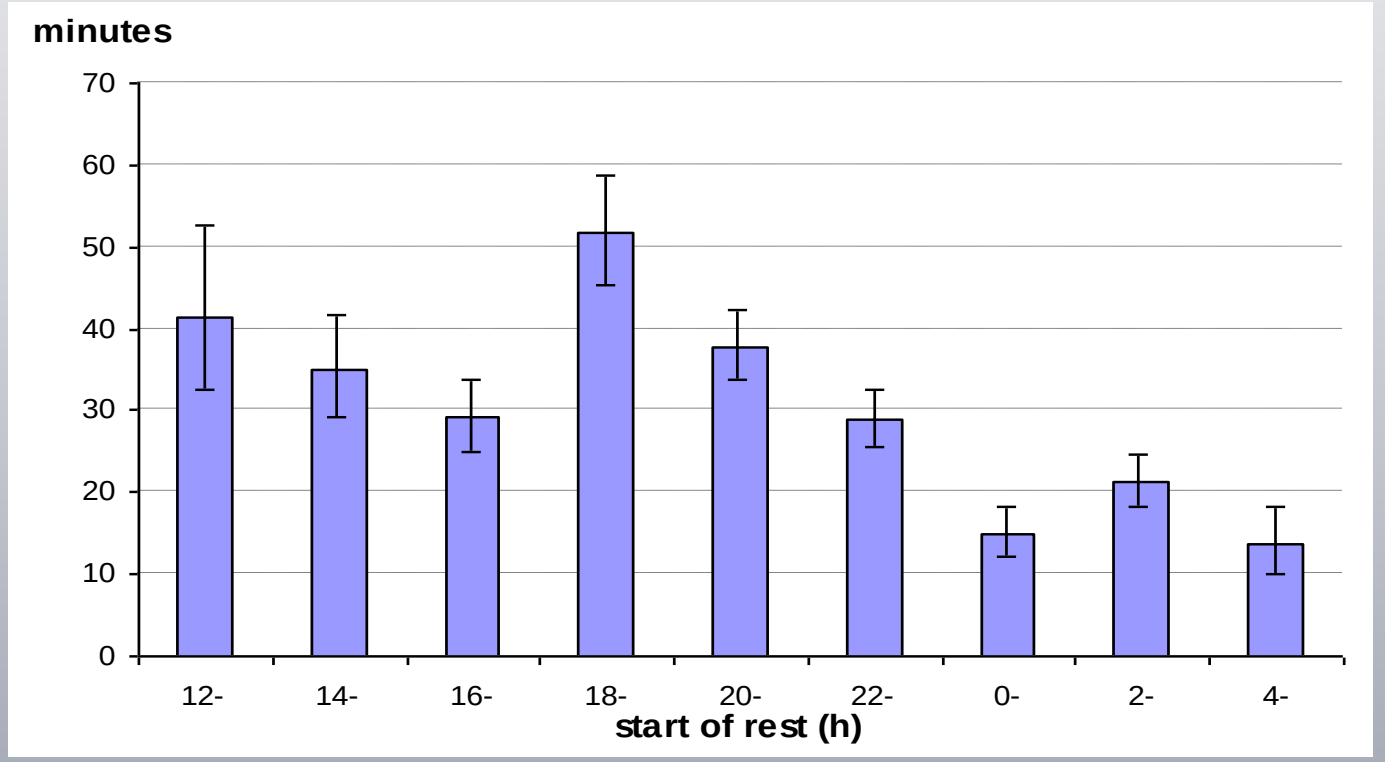
Organisation of in-flight rest



Duration of bunk sleep when acclimatised (outward flights)



Sleep onset time for bunk sleep (outward flights)



Sleep onset short during normal sleep time and longest during the 'forbidden zone' for sleep

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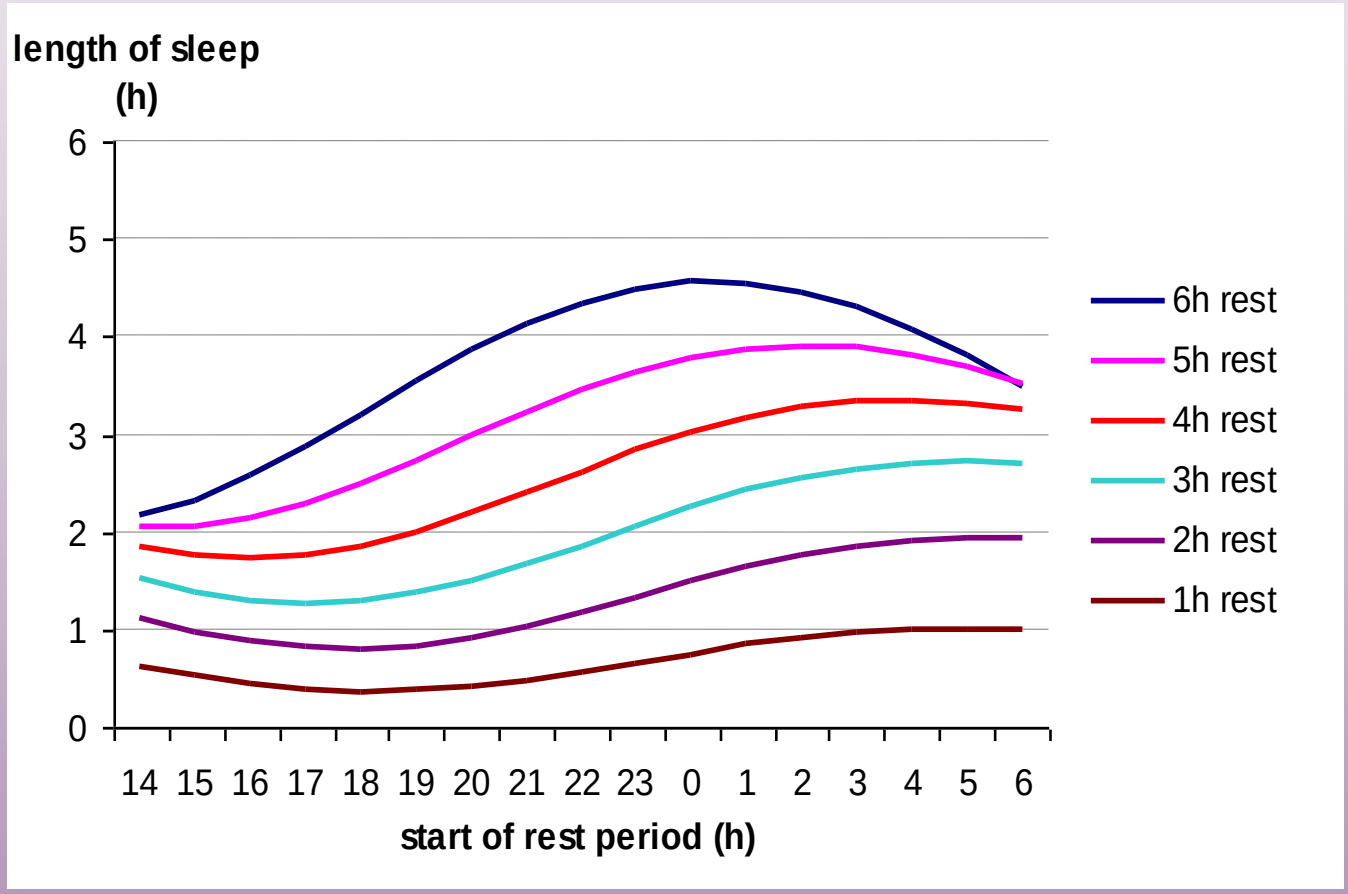
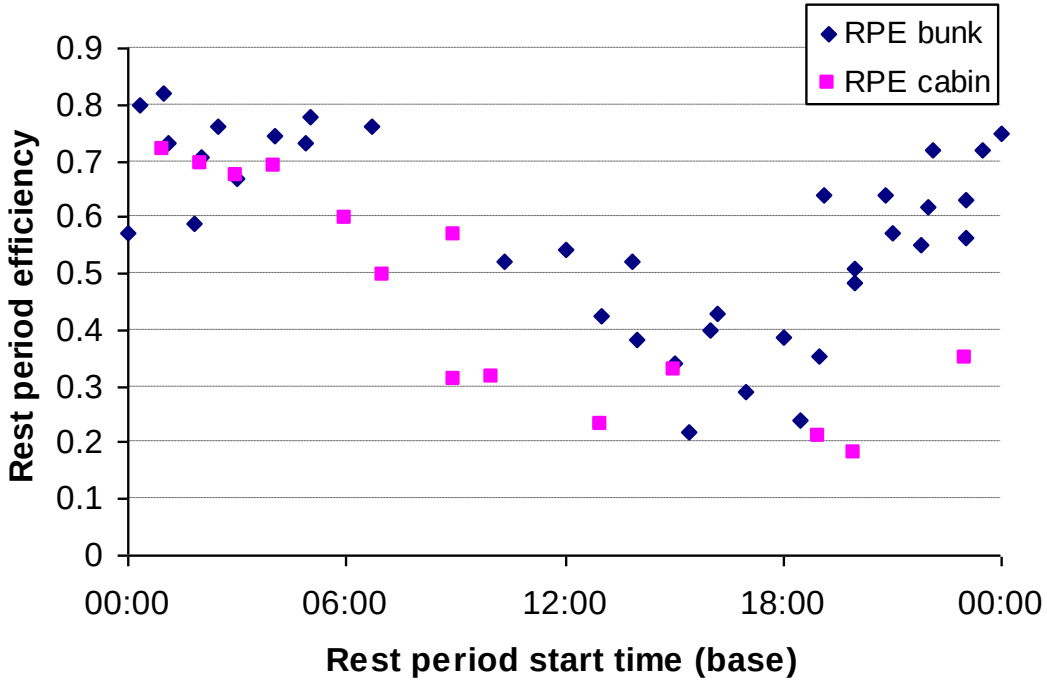
Model for the duration of bunk sleep



In flight disturbances bunk vs seat in the passenger cabin

	% cabin	% bunk	Probability
Using earplugs	46	36	0.030
Using eyeshades	63	14	<0.001
Difficulty getting to sleep	44	33	0.020
Difficulty remaining asleep	46	37	0.048
Requiring more sleep	53	39	0.003
Disturbed by:			
Aircraft noise	22	27	0.439
Random noise	30	39	0.053
Turbulence	39	30	0.011
Not feeling tired enough	13	17	0.488
Other people	40	21	<0.001
Other	19	22	0.439

Sleep efficiency in Bunk vs Seat



- Sleep on board is better in a bunk particularly outside normal sleeping hours

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Fatigue Measurement Scale

Samn Perelli Subjective Fatigue Scale

1. Fully Alert, wide awake
2. Very lively, responsive, but not at peak
3. OK somewhat fresh
4. A little tired, less than fresh
5. Moderately tired, let down
6. Extremely tired, very difficult to concentrate
7. Completely exhausted, unable to function

Other Scales

- Karolinska sleepiness scale
- Karolinska Probability
- Missed responses
- Vigilance degradation
- Complex vigilance degradation test
- 100 point alertness scale
- Etc.

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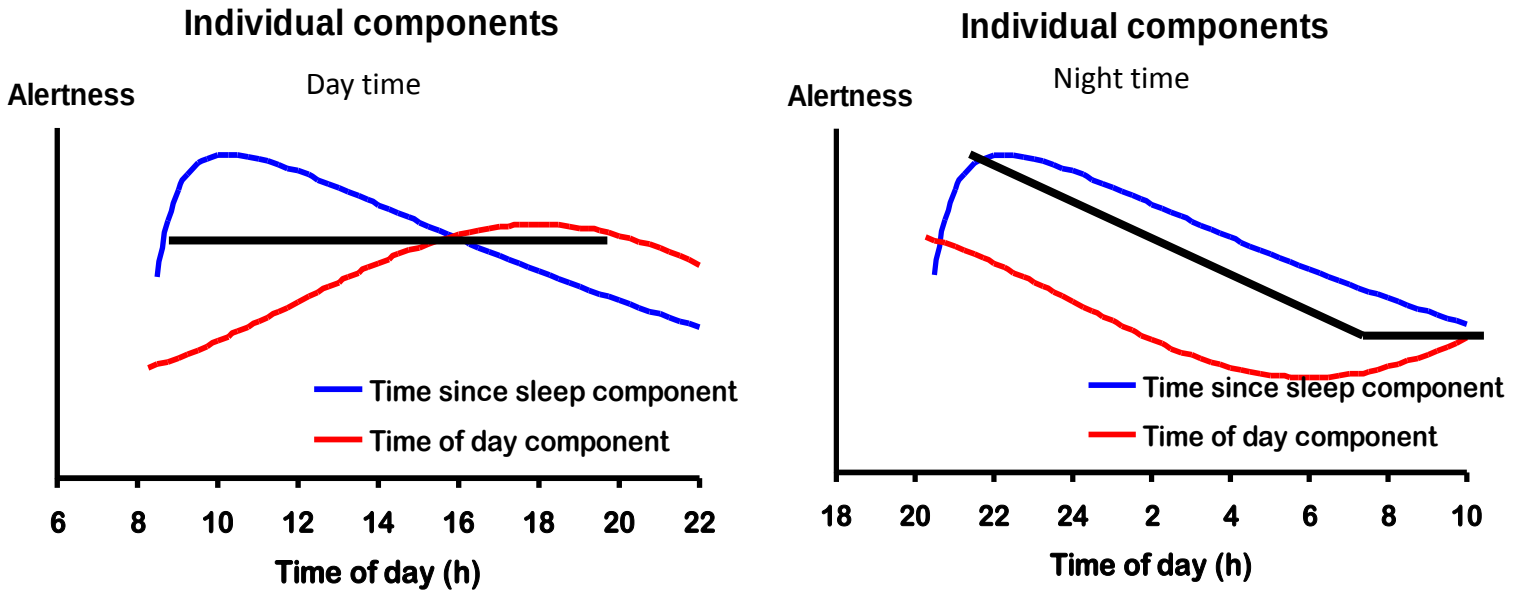
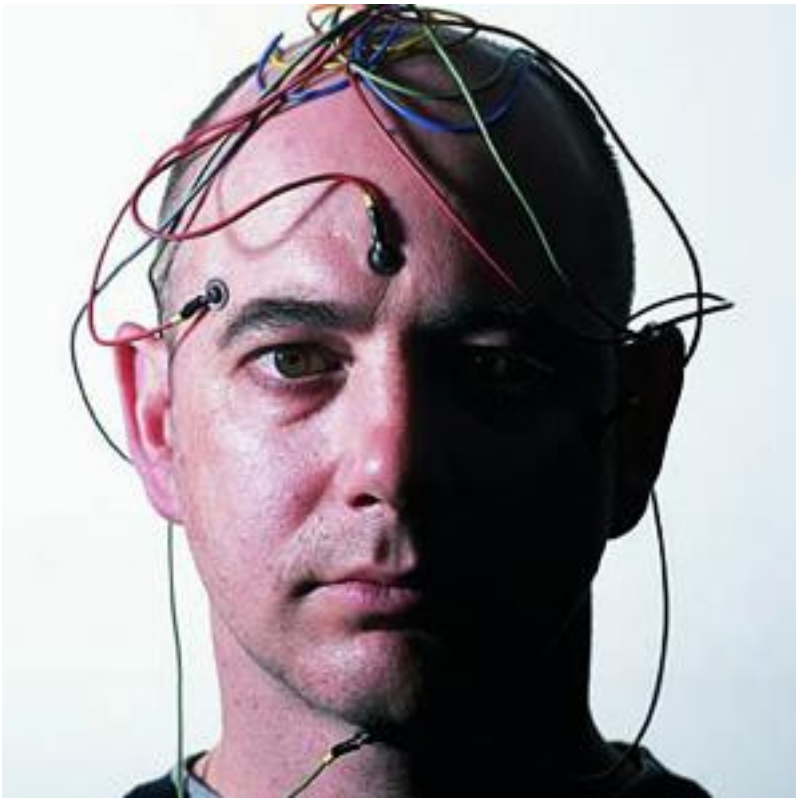
Main drivers of fatigue - acclimatised



The combined effect of the components of fatigue leads to an **approximately flat level of alertness** throughout the working day and a **steady decline in alertness** during normal period of sleep; flattening at the time where the circadian rhythm begins to rise in the early morning

What to look for in a bio-mathematical model

- Robust science
  - Including components for time since last sleep, circadian rhythm (time zone transitions), sleep inertia (in flight rest)
- Validated for the **target occupation** and data entry requirements
  - Objective and subjective data collection with EEG
- Software built to commercial quality standards
- Acceptable predictions (sleep and fatigue)
- Ability to model scenarios
- Ease of use
- Ongoing development



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When to use models in the context of acclimatisation

- As a first step to identify and scale the fatigue hazard inherent in future roster design
- To assess the fatigue impact of a new route or operation e.g. proposed change of departure time
- To check the likely quality of sleep on board the aircraft and the predicted fatigue for each pilot
- To assess the effect of different layover durations on fatigue during the return flight
- To investigate fatigue reports

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Background to the development of the SAFE suite of models

1987
IAM
Alertness
Model

- Alertness Model originally developed for Ministry of Defence (Spencer MB (1987) Ergonomics)
  - Later refined using data from volunteer studies leading to the development of SAFE prototype
  - Distributed widely within the aviation industry for review (beta version) 2001 Formally used by **UK CAA** from 1999
  - Validation studies in CAT and cargo aircrew undertaken to improve the model estimates
  - Extrapolated predictions used by CAA Singapore for first **ULR** routes
  - FRMSc launches SAFE v 5.5 January 2012
  - FRMSc launched cabin crew model **CARE** in February 2013.
  - Validated for Air Taxi and emergency medical services with studies undertaken 2014 to 2015
  - "Business jets", rotary wing, maintenance engineering and ATC models planned.

1982
Early
studies

1994
SAFE
Prototype

2003
SAFE
Programme
version 5.0

2012
SAFE
Programme
version 5.5

Validation studies

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What the SAFE – CARE models do

- Forecast the likely fatigue of the average aircrew for the roster/schedule under consideration

  (SAFE = Pilots; CARE = Cabin crew)
- Provide a fatigue score every 15 minutes of duty
- Up to 12 months of rosters (history or forecast) can be analysed
- About 150,000 duties can be uploaded in a single file –or driven directly from rostering suite
- Provides an easy to understand display.

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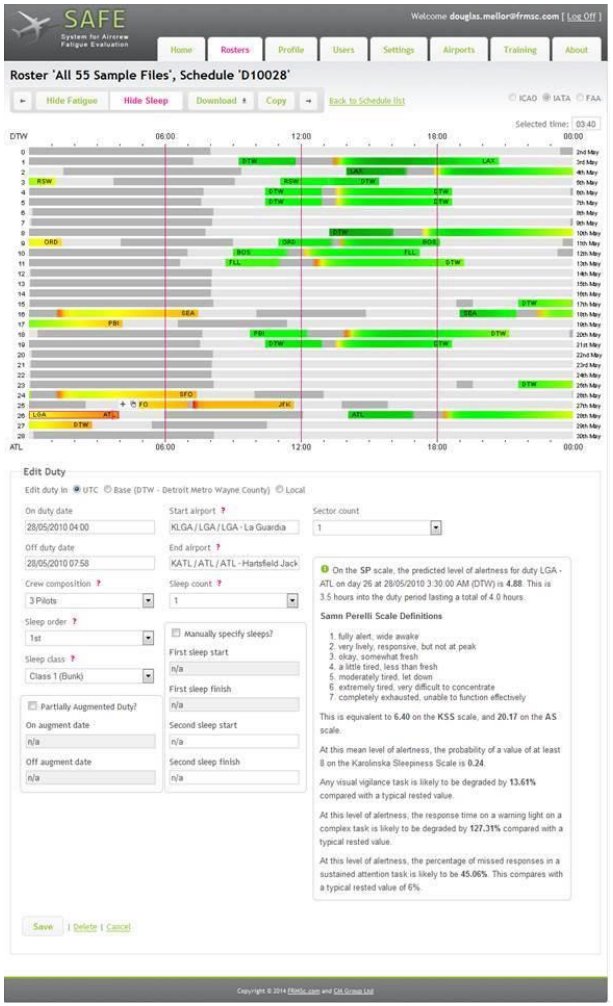
Features of SAFE

- Customized alertness model designed specifically for the aviation industry
- A cloud based solution from v 5.5 with integration into rostering platforms. Hosted on Microsoft Azure Cloud
- In use by Regulators.
  - Used daily by UK CAA and other regulators. Simple data entry requirements
  - Validated from studies with real Air Crew
  - International collaboration including, PAN AM, Singapore, Air New Zealand, Emirates, Japan Airlines, Britannia, Lufthansa, British Airways, Cathay Pacific, DHL.



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Long-haul operations

- Data collected to establish impact of different Crew Operating Patterns on crew alertness
  - Investigate the extent of the disruption to crews on different long-haul routes
- Concerned principally with:
  - sleep disturbance (e.g. on layover and on recovery)
  - circadian adaptation
  - the recuperation provided by in-flight rest including sleep inertia

Input Data Requirements

Reference	On duty date	On duty time	Start airport	Off duty date	Off duty time	End airport	Sectors	Crew composition	Sleep count	Sleep order	Sleep class	Home base	Timezone
Pilot	01/05/2010	18:35:00	JFK	02/05/2010	06:40:00	SVO	1	3	1	1	1	JFK	1
Pilot	03/05/2010	06:35:00	SVO	03/05/2010	18:55:00	JFK	1	3	1	1	1	JFK	1
Pilot	07/05/2010	21:50:00	JFK	08/05/2010	09:20:00	BUD	1	3	1	1	1	JFK	1
Pilot	10/05/2010	09:15:00	BUD	10/05/2010	21:25:00	JFK	1	3	1	1	1	JFK	1
Pilot	11/05/2010	21:25:00	JFK	12/05/2010	08:10:00	TXL	1	3	1	0	1	JFK	1
Pilot	14/05/2010	07:55:00	TXL	14/05/2010	18:55:00	JFK	1	3	1	1	1	JFK	1
Pilot	15/05/2010	23:10:00	JFK	16/05/2010	10:10:00	PSA	1	3	1	1	1	JFK	1
Cabin crew	01/05/2010	18:35:00	JFK	02/05/2010	06:40:00	SVO	1	9	1	1	1	JFK	1
Cabin crew	03/05/2010	06:35:00	SVO	03/05/2010	18:55:00	JFK	1	9	1	1	1	JFK	1
Cabin crew	07/05/2010	21:50:00	JFK	08/05/2010	09:20:00	BUD	1	9	1	1	1	JFK	1
Cabin crew	10/05/2010	09:15:00	BUD	10/05/2010	21:25:00	JFK	1	9	1	1	1	JFK	1

On partial augment date	On partial augment time	Off partial augment date	Off partial augment time	First rest start date	First rest start time	First rest end date	First rest end time	Second rest start date	Second rest start time	Second rest end date	Second rest end time
				12/05/2010	00:00	12/05/2010	04:00				

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Cabin Crew Alertness and Rest Evaluation (CARE) model

Differences between pilots and cabin crew

- Workload
- Rest period timing
- Rest accommodation

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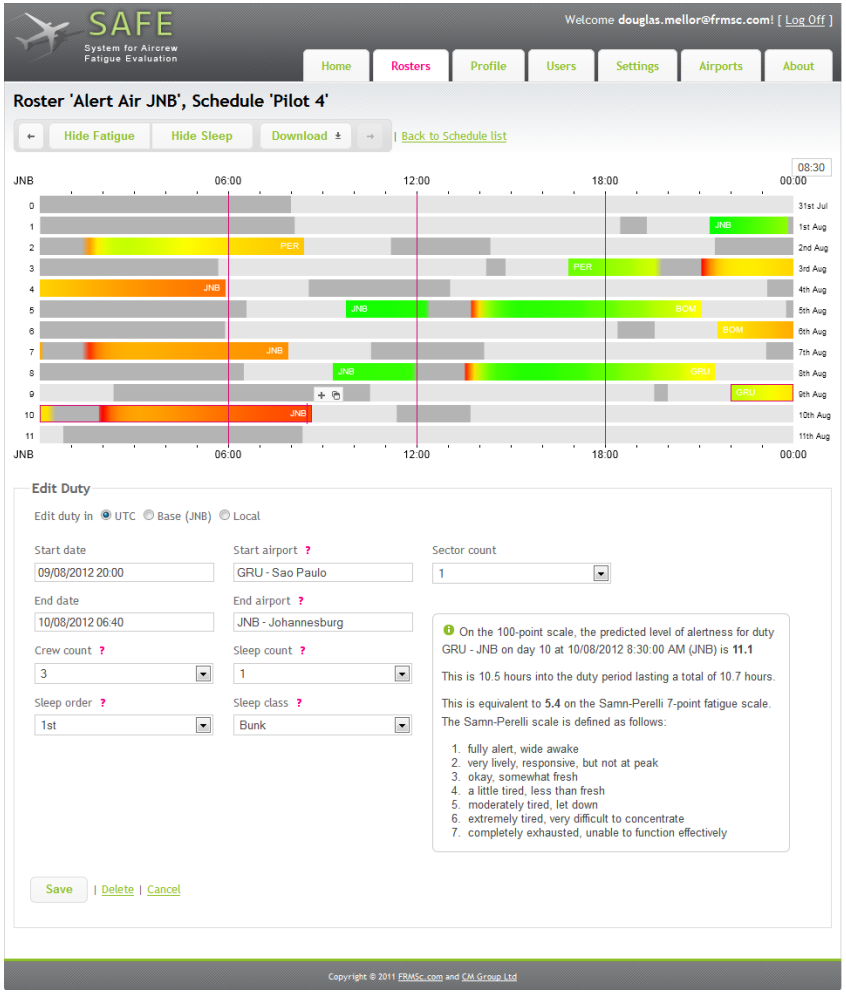
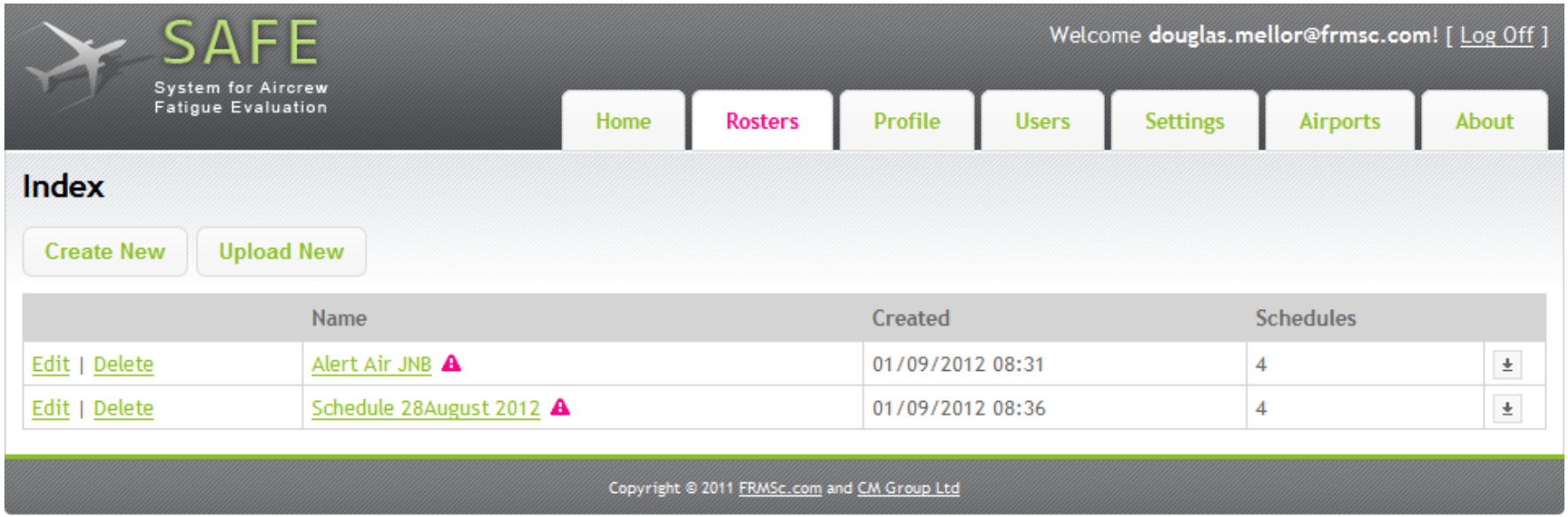
USING SAFE: EXAMPLES



Example of a schedule analysed by SAFE



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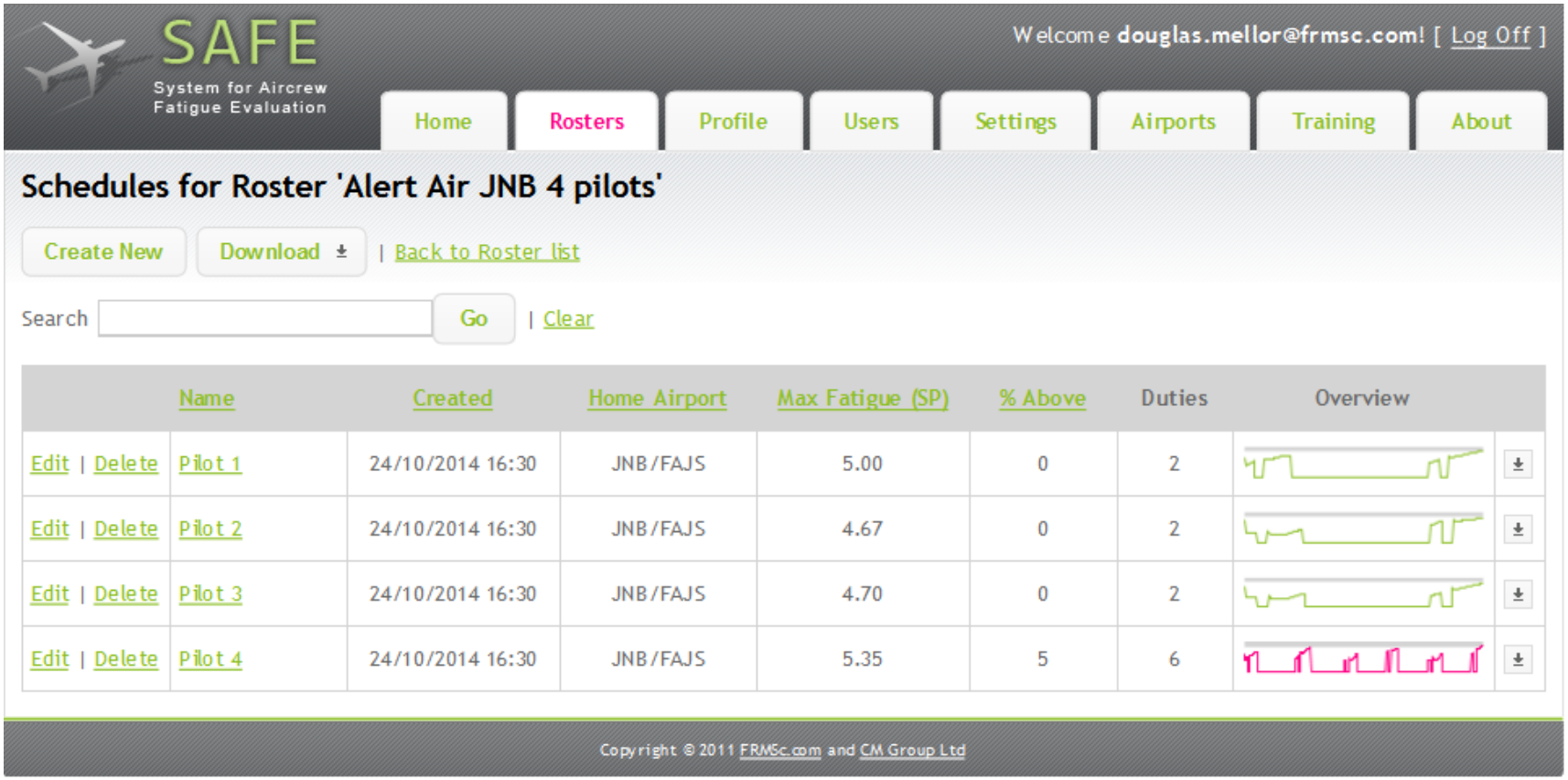

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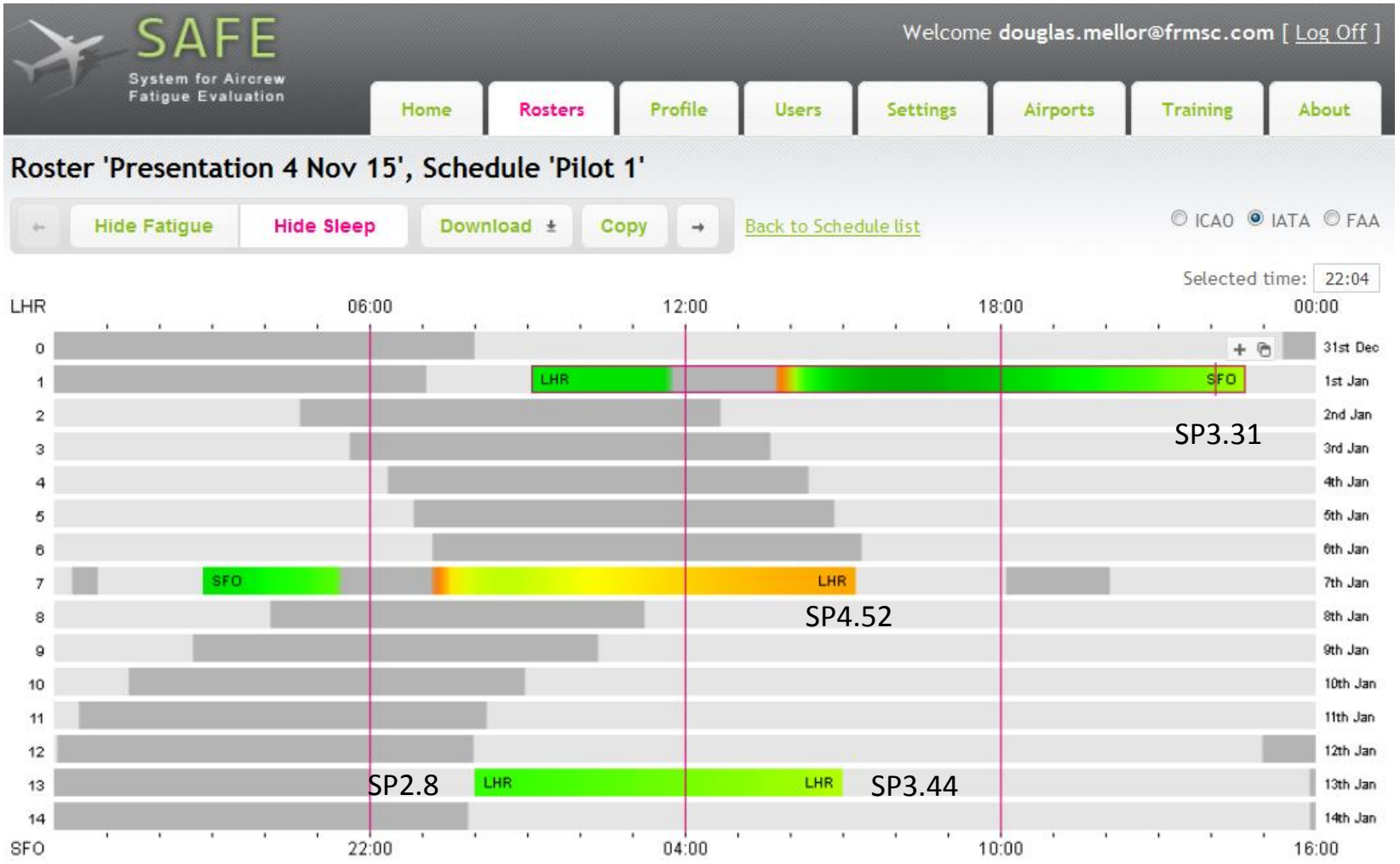
Westward Time Zone change first -3 pilots and first sleep (5 day layover)



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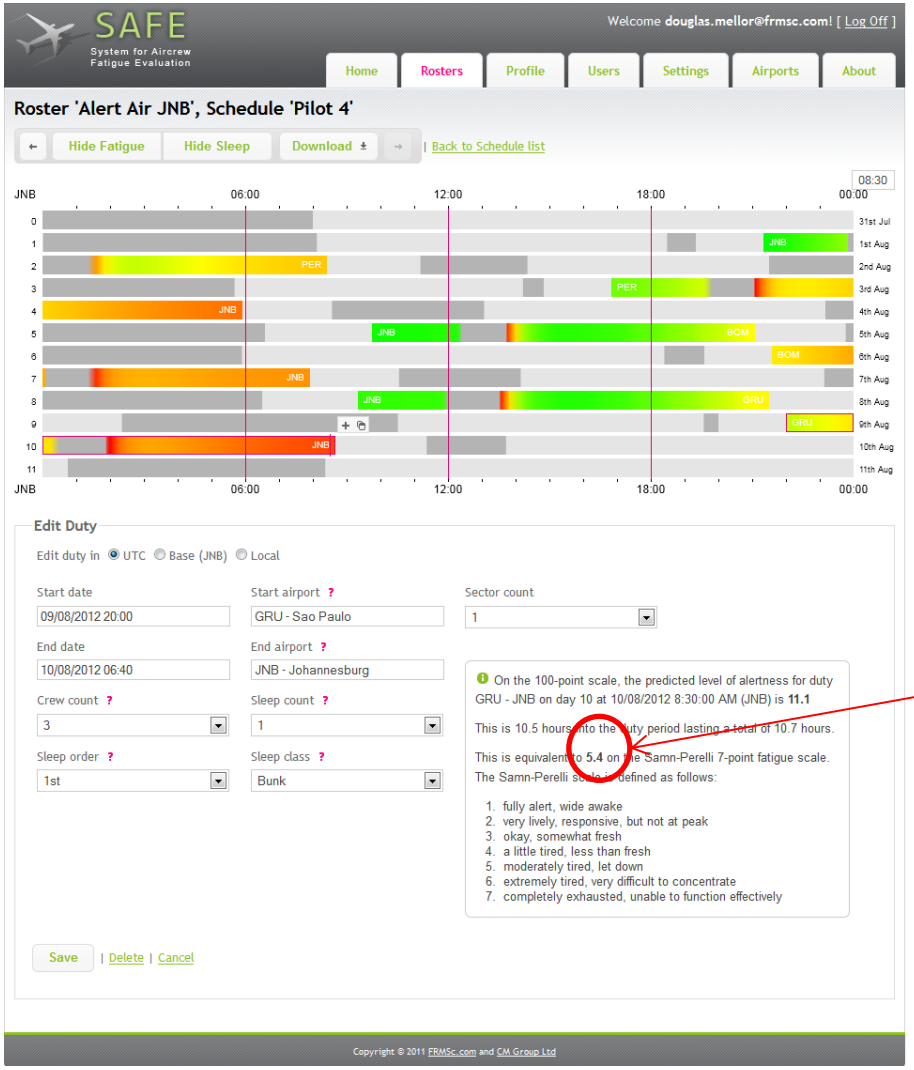

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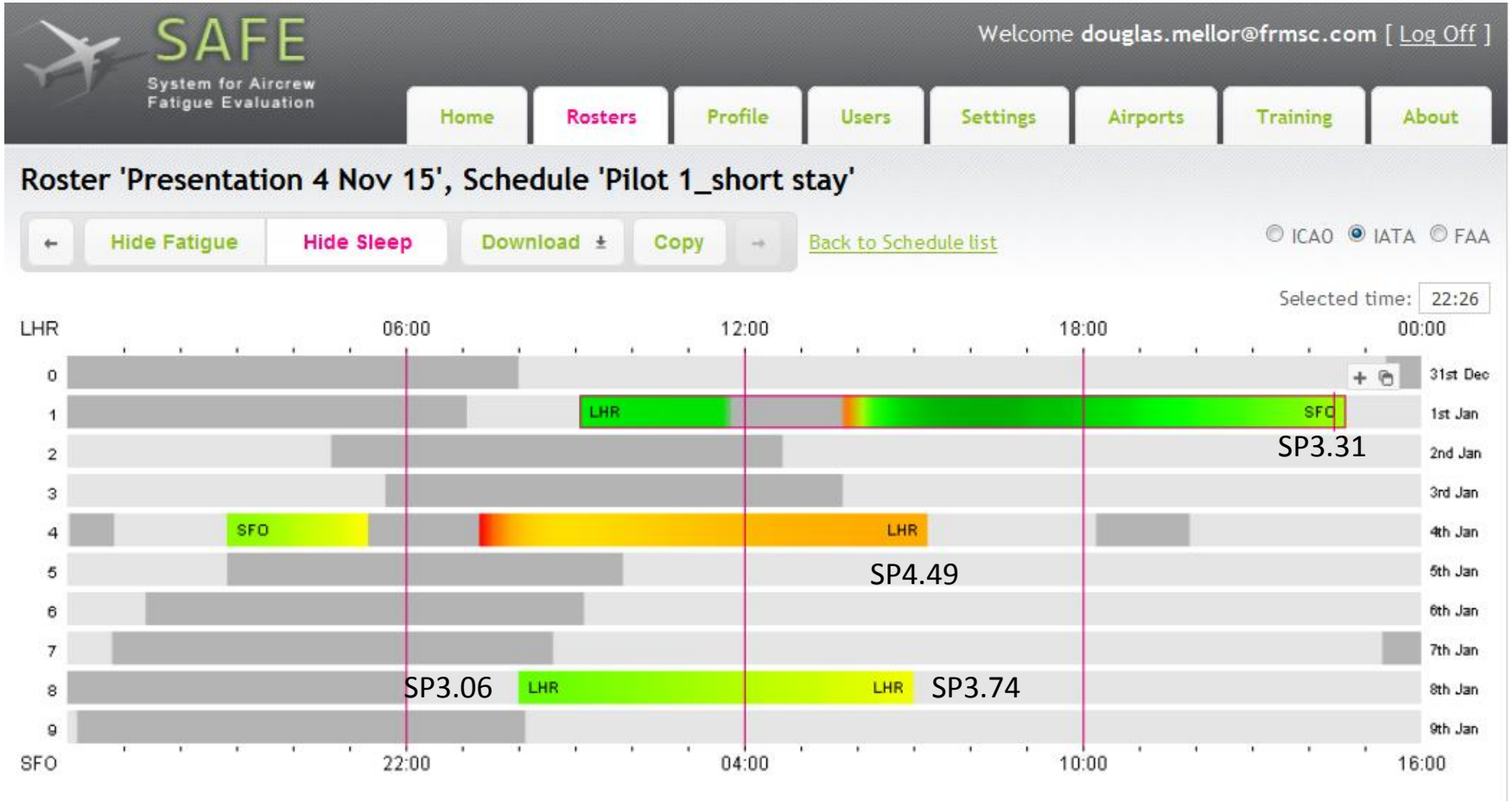
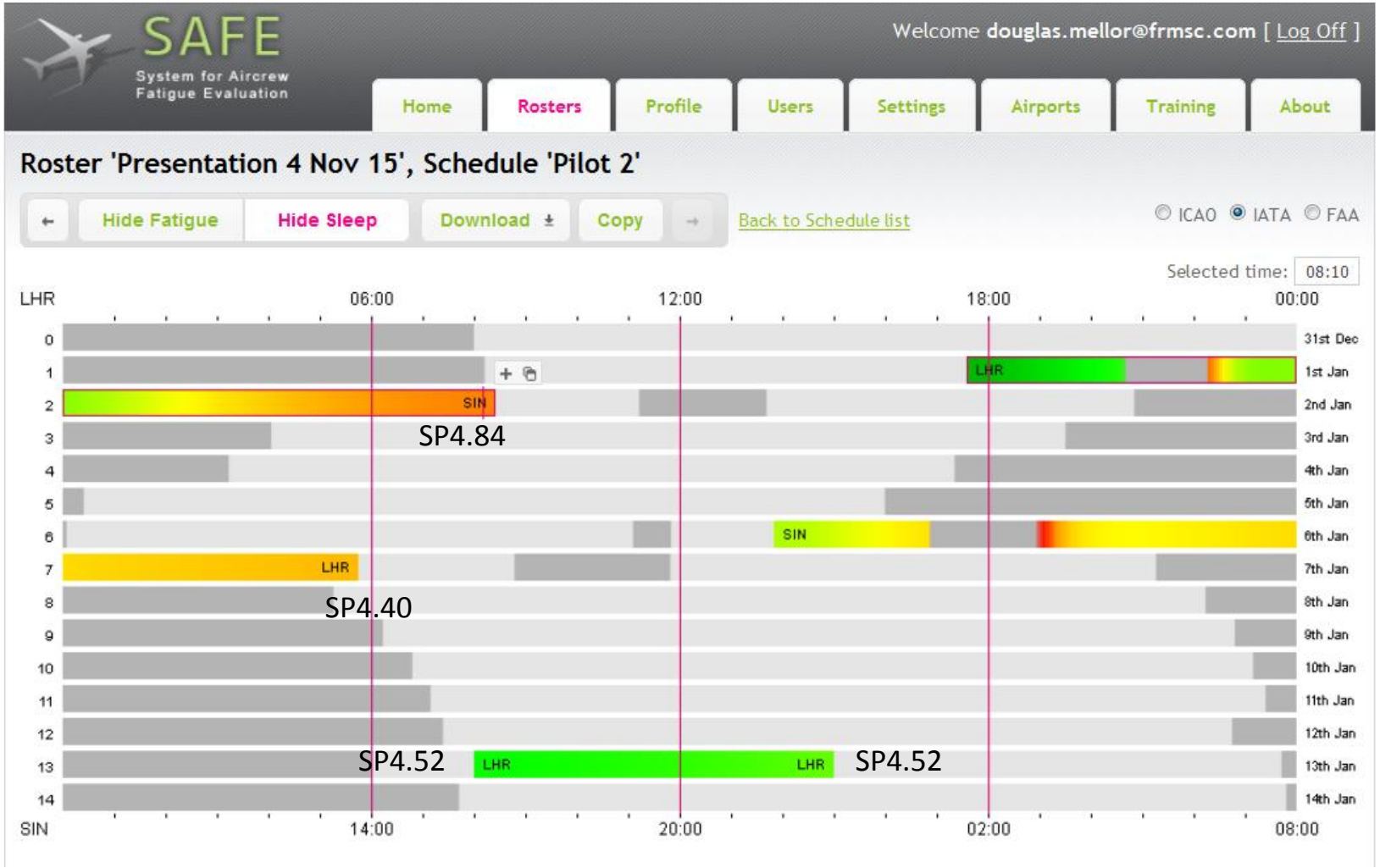
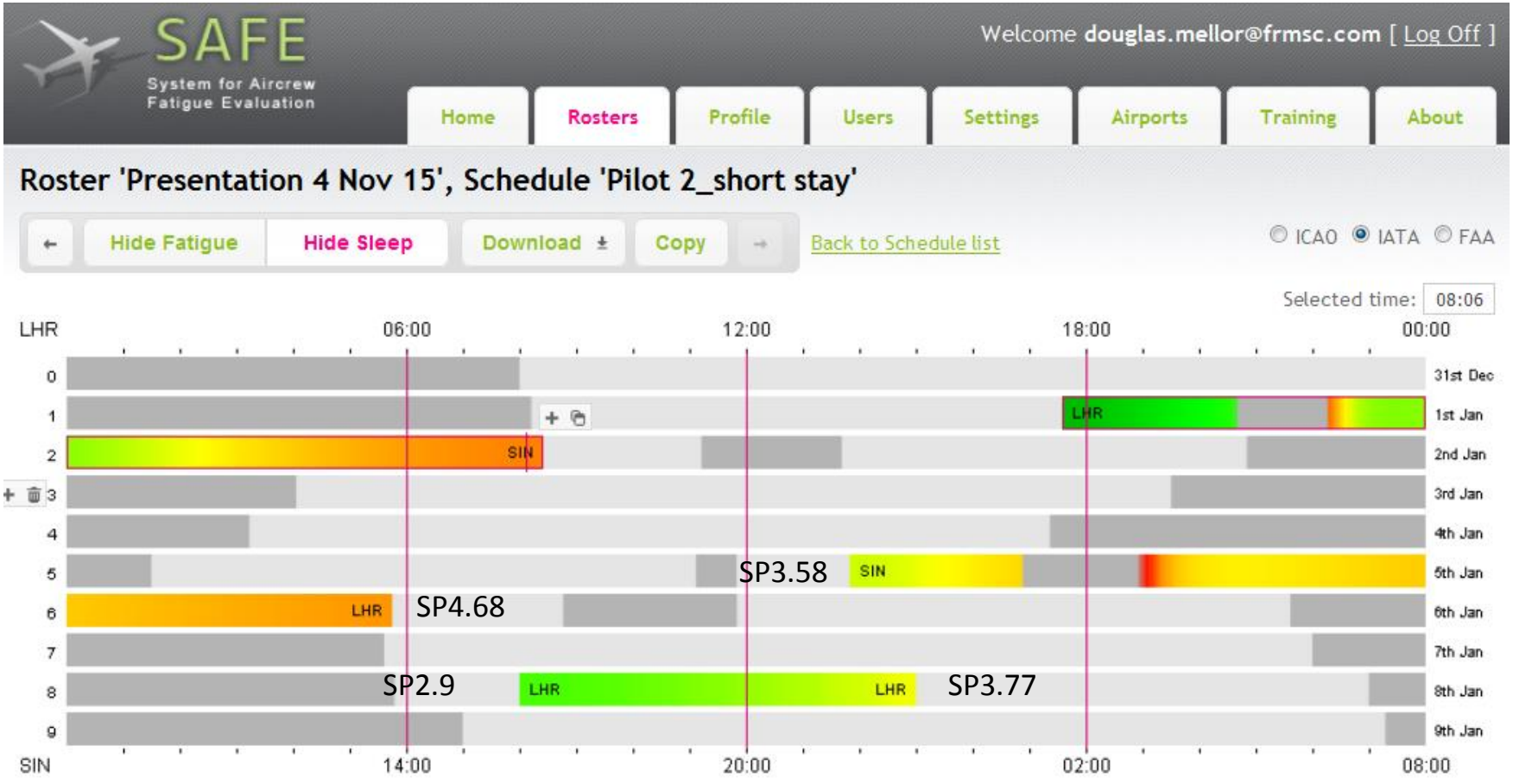
Westward Time Zone change first – 3 pilots and first sleep (53h layover)



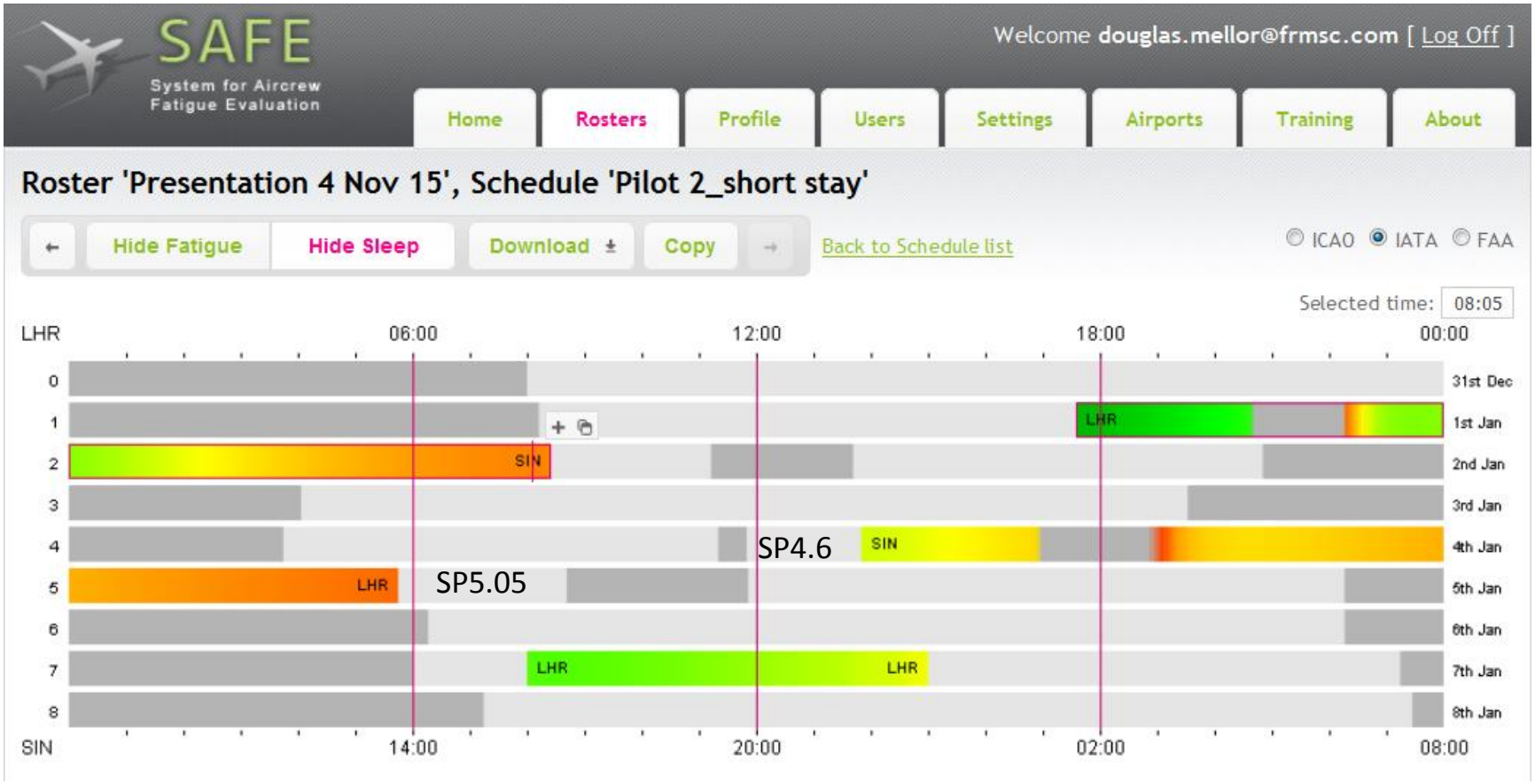
Eastward time Zone change first – 3 pilots and first sleep (4 day layover)



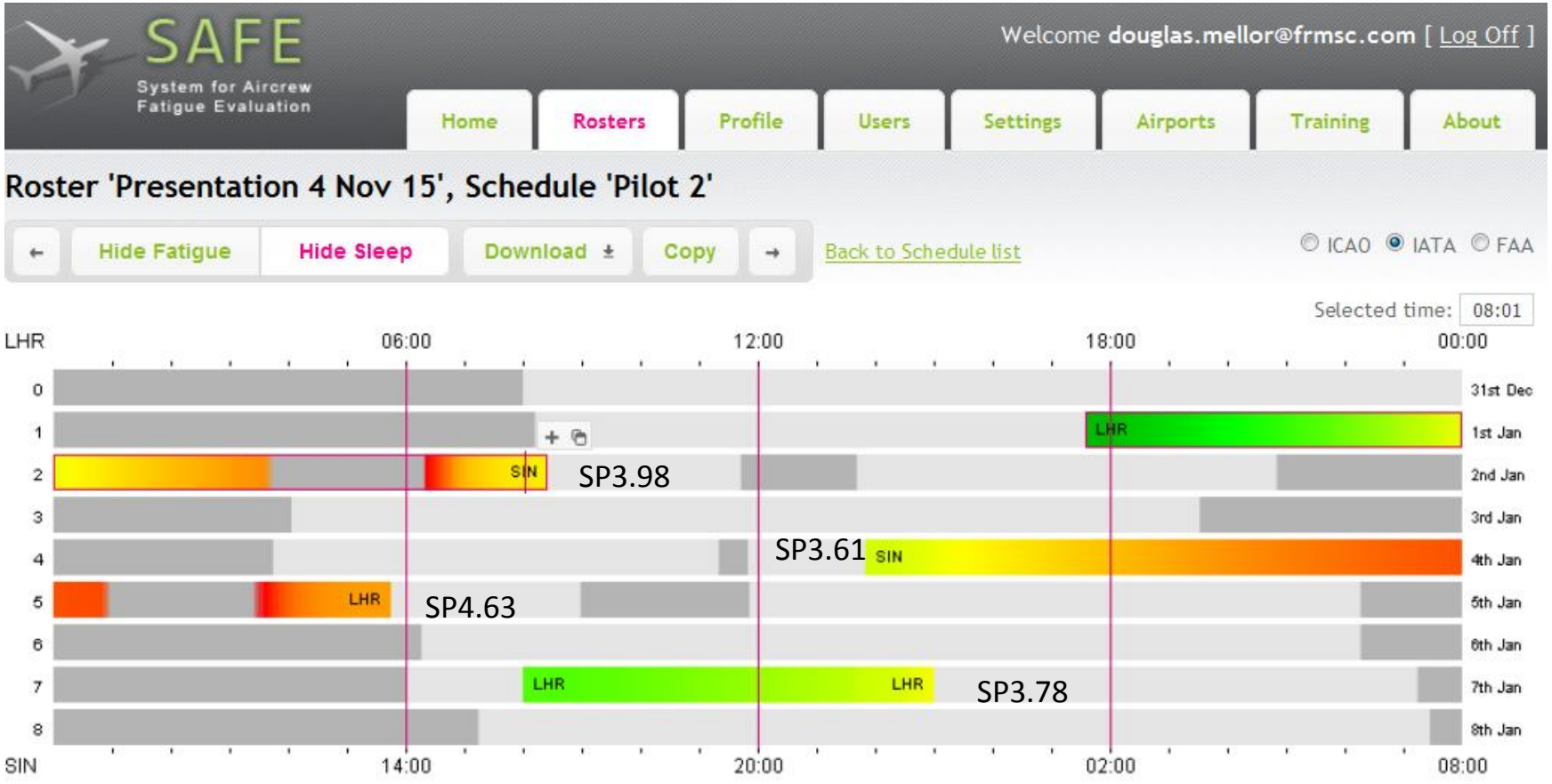
Eastward time Zone change first – 3 pilots and first sleep (3 day layover)



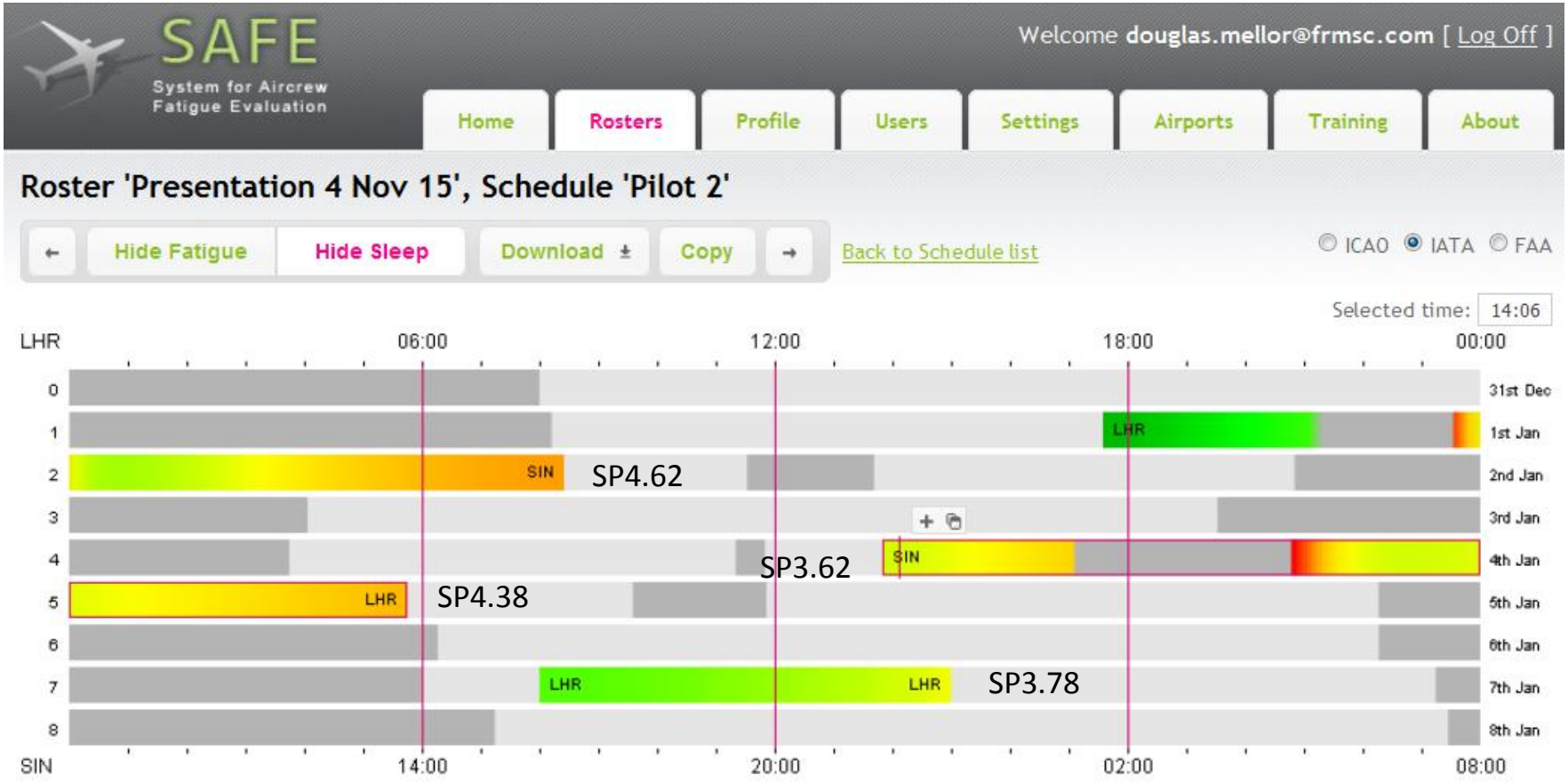
Eastward time Zone change first – 3 pilots and first sleep (2 day layover)



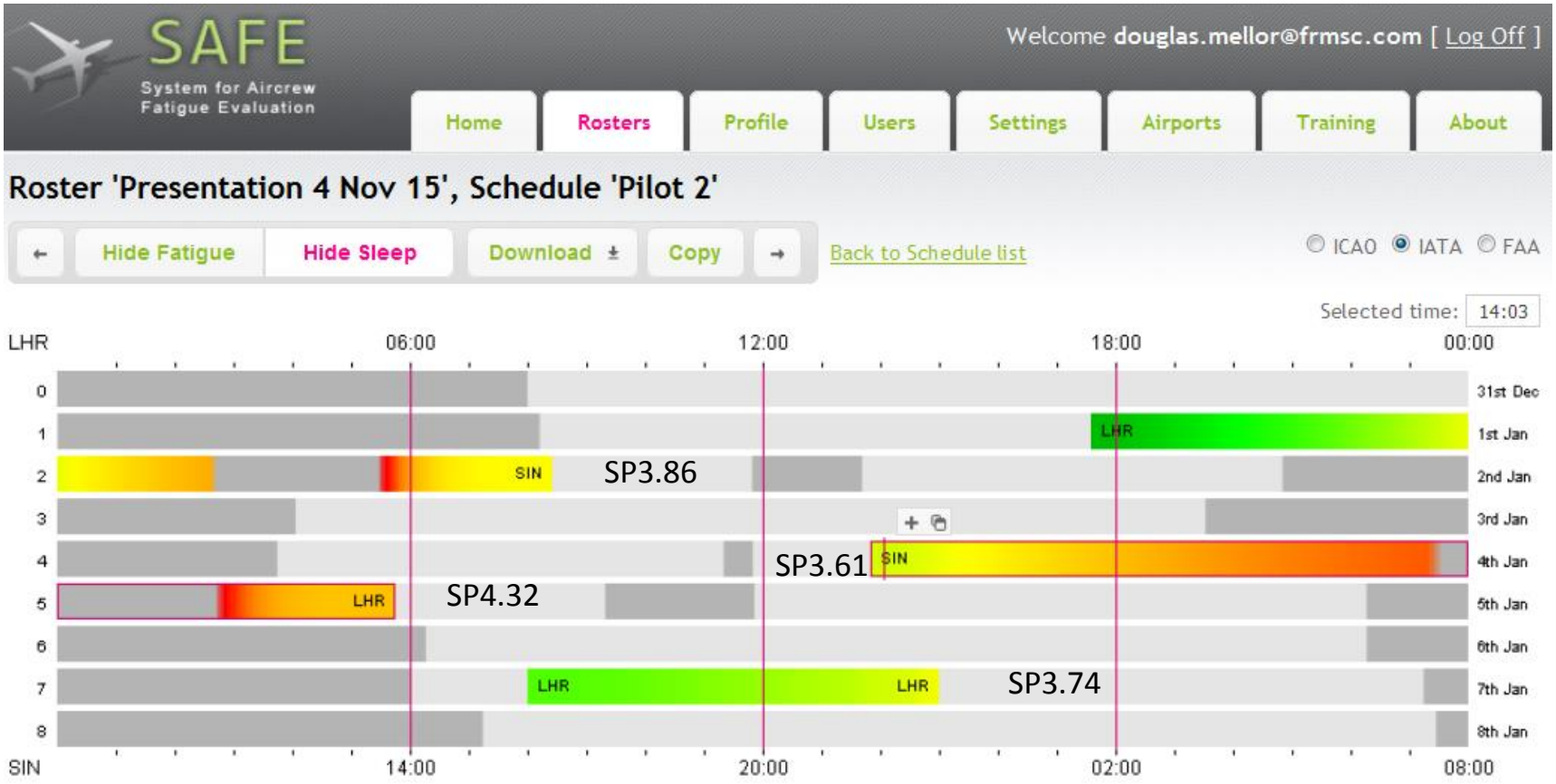
Eastward time Zone change first – 3 pilots and first sleep (2 day layover) 3rd sleep position



SIN 4 pilots 1st position bunk



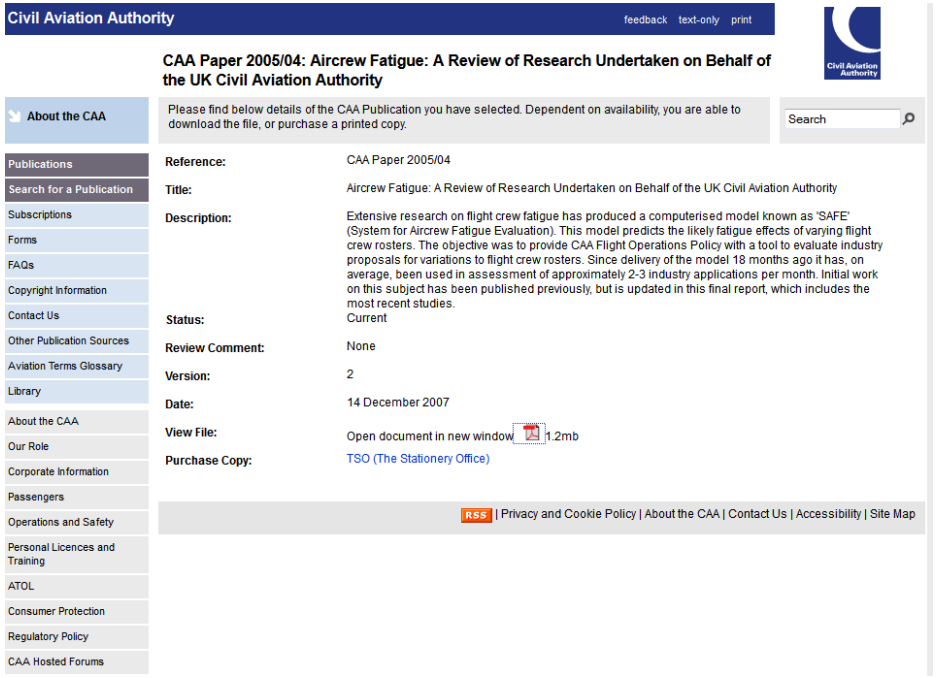
SIN 4 pilots 2nd position bunk



SAFE: Research Studies

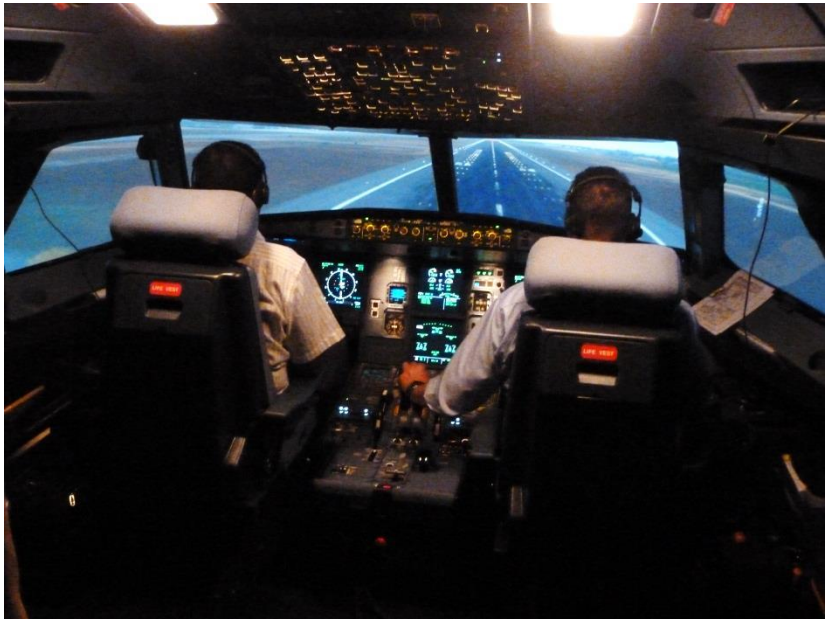
To view a large proportion of the research incorporated into SAFE, go to:

http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=1942



Summary

- Aircrew rarely fully acclimatise to rapid time zone changes
- Sleep on layover more disturbed following eastward travel
- Sleep on board influenced by quality of sleep facility and timing
- Bio-mathematical models can be used to simulate different flight departure times, different layover durations and the effect on sleep and fatigue
- The effect on fatigue of changing crew size, sleep location or sleep order can be tested



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Thank you for listening

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