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# Harmonized AutoSleep

*Improving Fatigue Modeling by Increasing Accuracy of Sleep Estimates*

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## Author Acknowledgement

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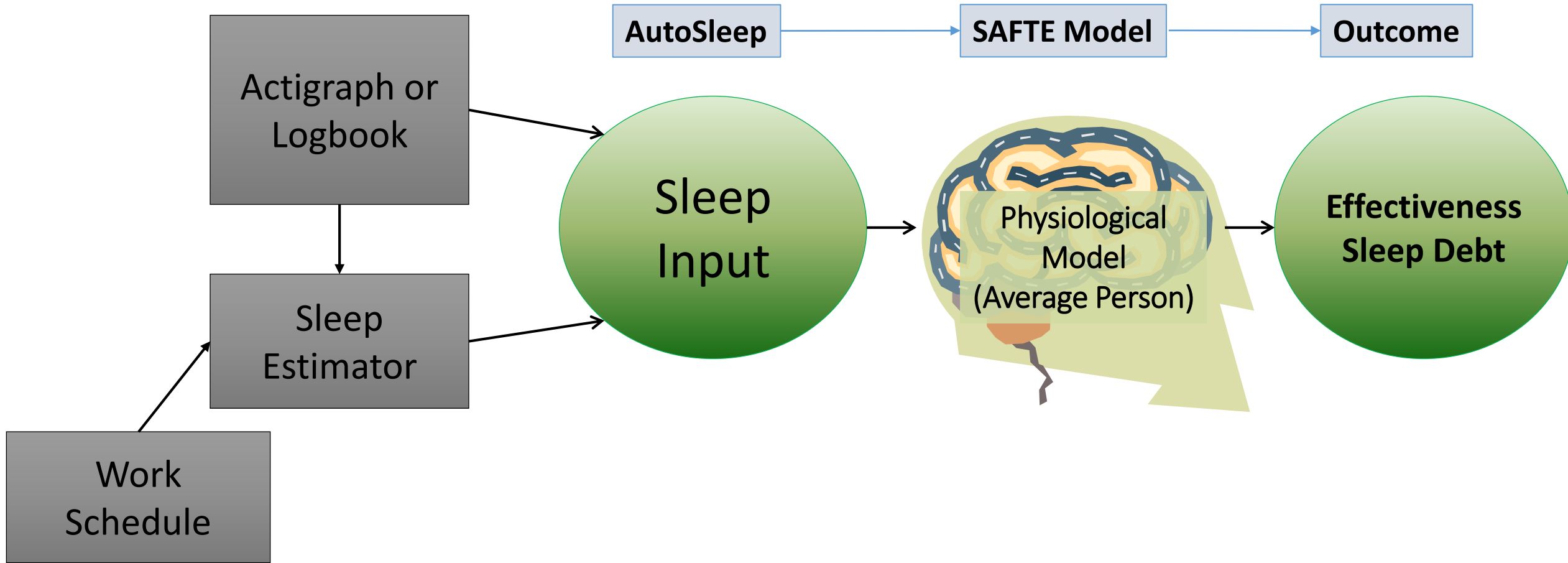


# Introduction

- Accurate sleep prediction is essential for forecasting fatigue using bio-mathematical fatigue models.
- AutoSleep is the sleep estimator in SAFTE-FAST, a behavioral decision model of average sleep decisions under operational constraints.
- There are nine discrete parameters that control the decisions rules.
- The Harmonizer finds the best set of parameters for a given pattern of sleep.



# Two-Step Model of Sleep and Performance

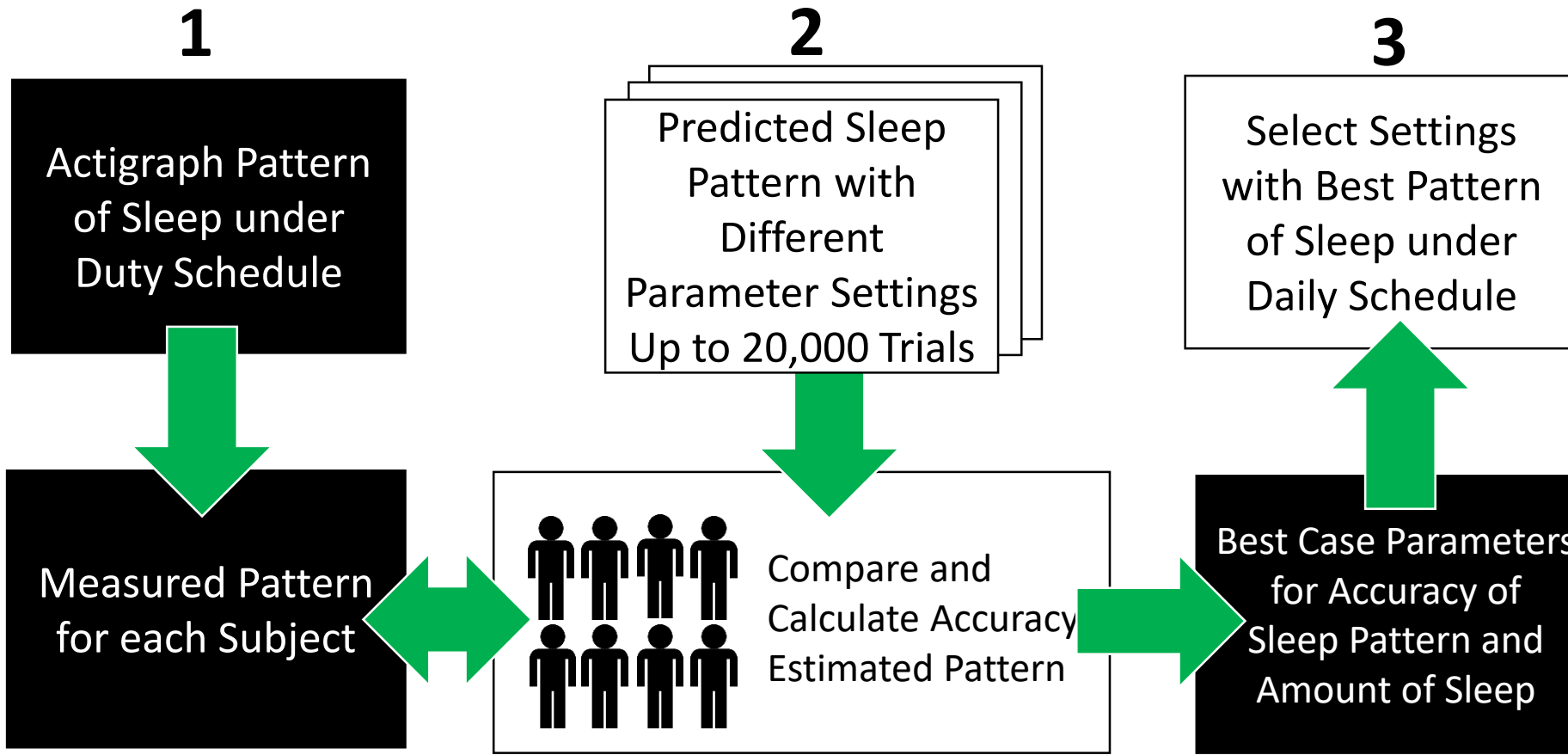
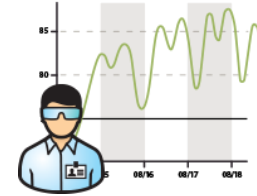


# Two Studies – Civilian Airline Pilots and Military Pilots

- Civilian Airline Study
  - 22 Cases
  - Up to 3 Time Zones Changes
  - 7-10 days per case
- Military Aviation Study
  - 22 Missions
  - Up to 10 Time Zones Changes
  - 91 subjects, Mean TIB Across Subjects
  - Average 9 study days per mission (6 days of duties)



# Refining Sleep Estimation, Sleep Harmonizing Process

**How we did it!**

1. We created all combinations (1 to N) of Parameters & Patterns
2. Rated each Pattern for Accuracy
3. Select Best Parameters based on Accuracy of Predicted Sleep



# Criteria for Accuracy

1. Amount of Sleep: Total amount of sleep predicted versus measured by actigraphy
  2. Accuracy of Sleep Pattern: Minute-by-minute percent correct identification of sleep minutes
- Overall Accuracy was combination of 1 and 2
  - Both criteria are necessary because it is important to make sure that what errors are present are not biased toward too much or too little sleep.



# Civilian Harmonizer Results

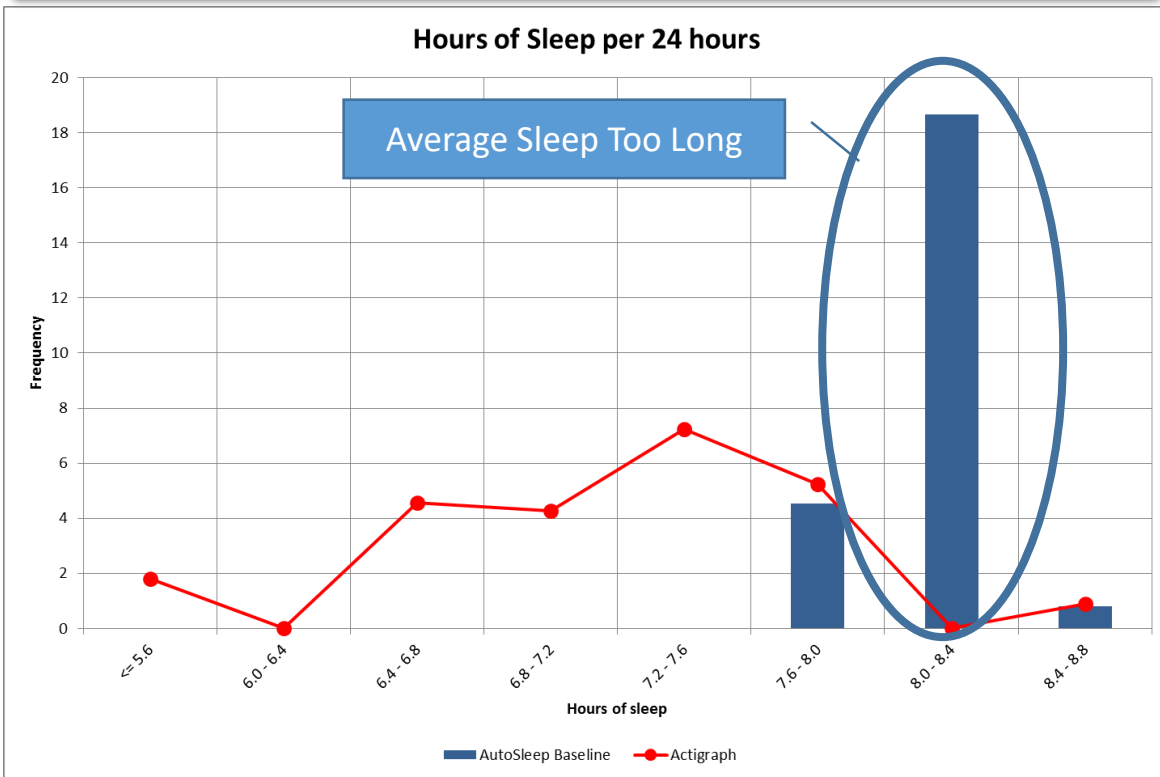
A photograph of a commercial airplane flying over the ocean at sunset. The sky is a mix of blue and orange, and the water is dark. The text "The Worldwide Leader in Aviation for Fatigue Management Solutions" is overlaid on the image in white.

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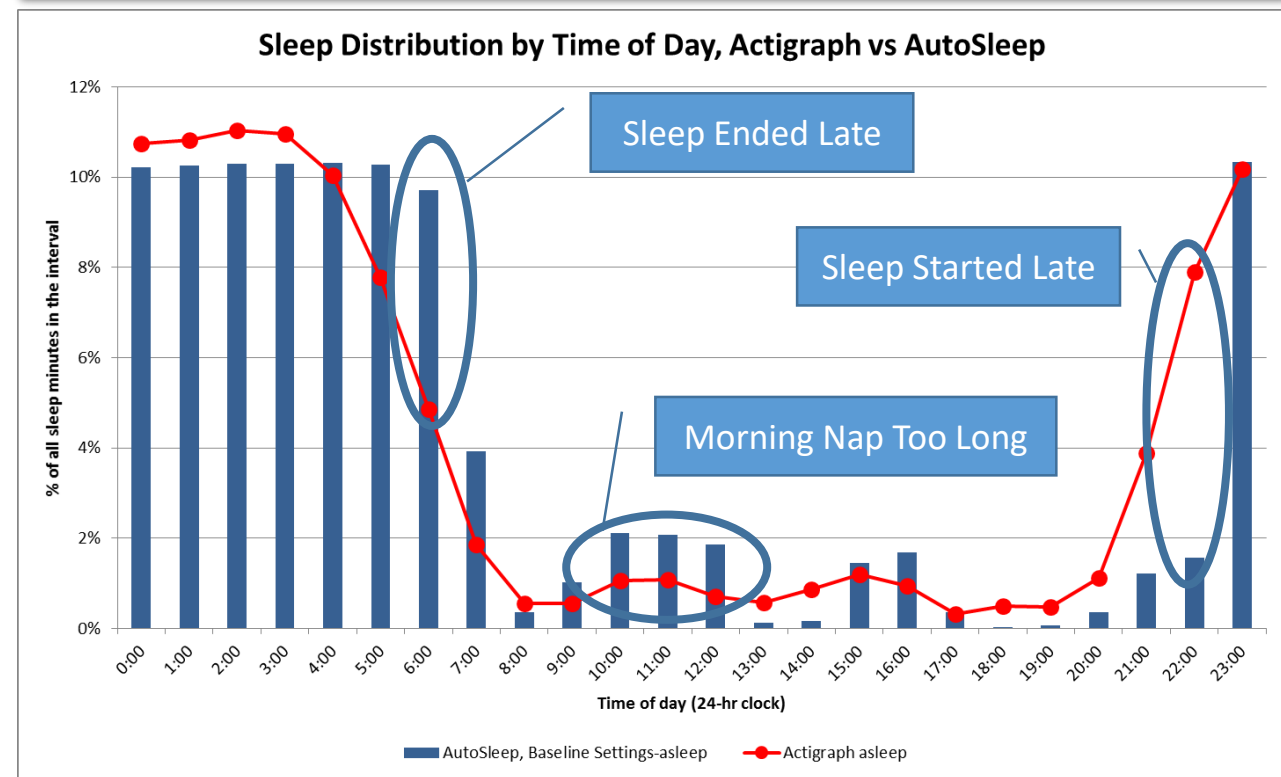


# Default AutoSleep

Default Settings Over-Estimates Sleep per Day by 30 min



Default Settings 85% Correct, Miss Early Bedtimes & Rise Times

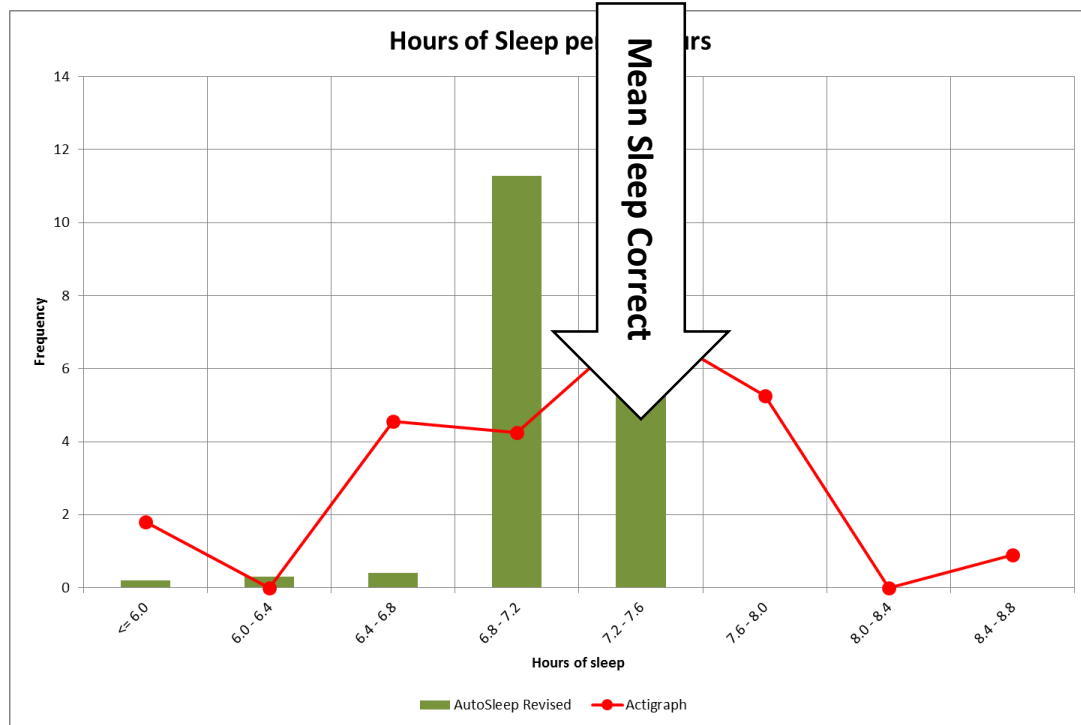


# Predicted & Actual Flight Crew Sleep

## Results of Multiple Harmonizer Runs and Algorithm Changes

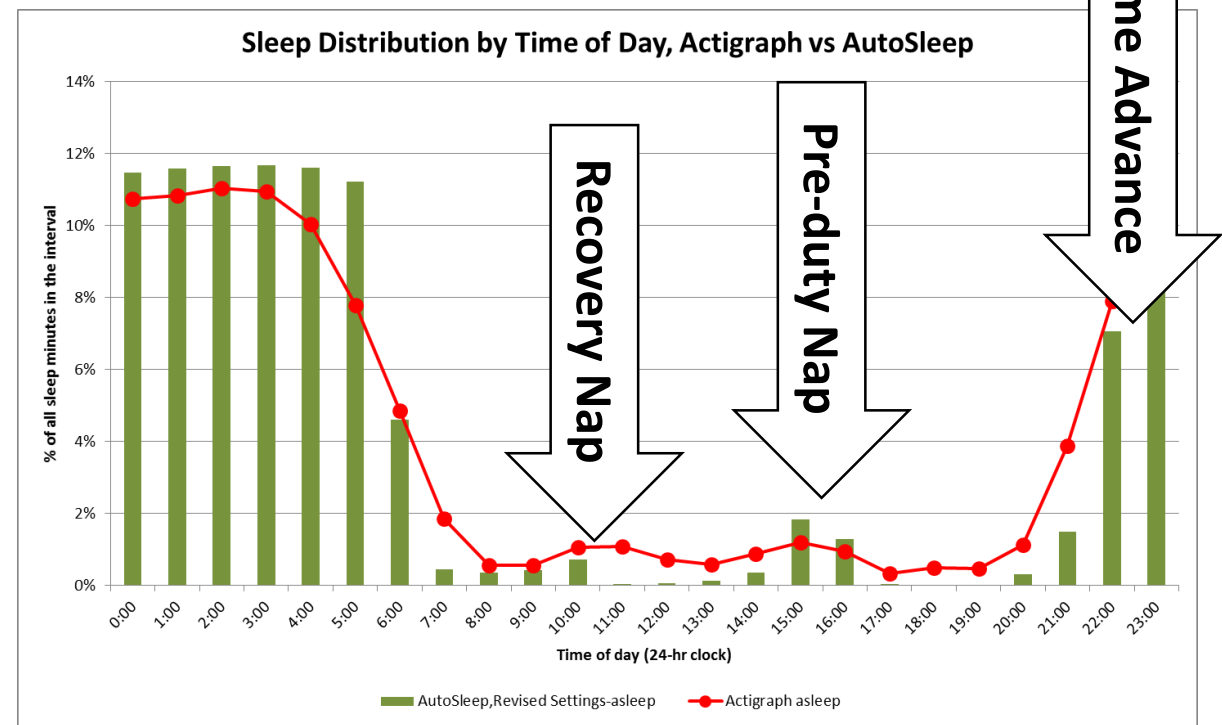
99% accurate for average sleep per day

Predicts the right amount of sleep



88% accurate across subjects at 1 minute resolution

Predicts the right pattern of sleep



# Harmonized Settings

Parameter	Default	Harmonized
Bedtime	23:00	22:30
Max Rest Day Sleep	540 min	480 min
Max Work Day Sleep	480 min	450 min
Awake Zone Start	13:00	11:00
Awake Zone End	19:00	19:00
Commute	60	90
Maximum Recovery Nap	210	120
Inflight Sleep Percentage	75%	60% of time
Min by Min Sleep/Wake Accuracy	85.63%	88.26%
Total Daily Sleep Accuracy	88.23%	99.97%



# Military Harmonizer Results

A photograph of a commercial airplane flying over the ocean at sunset. The sky is a mix of blue and orange, and the water is dark. The text "The Worldwide Leader in Aviation for Fatigue Management Solutions" is overlaid on the image in white.

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# Canadian Defence Air Force Study

## *22 Missions, 91 Subjects, Average 9 Days per Mission*

#	Mission ID #	N	Days	Mean Sleep Minutes TIB/Day
1	2520	3	12	496.8
2	2532	4	6	433.8
3	2536	3	13	453.0
4	2546	4	15	450.3
5	2559	4	11	444.2
6	2574	3	10	510.3
7	3102	5	8	417.4
8	3172	5	6	448.2
9	3313	3	9	442.4
10	3619	3	14	450.8
11	4018	3	7	435.9
12	4022	3	5	564.4
13	4023	5	7	564.6
14	4025	4	10	497.3
15	4028	4	5	440.6
16	4042	4	7	519.1
17	4057	6	8	474.5
18	4059	5	8	459.5
19	4061	4	8	464.8
20	4067	4	6	565.7
21	4077	4	11	508.4
22	4179	8	6	458.3
<b>Total or Mean</b>		<b>91</b>	<b>9</b>	<b>477.3</b>

For each mission, the sleep patterns of the aircrew were averaged and we harmonized to the 22 average patterns.



# Extended Commute Times

- Original harmonize trials done with maximum commute of 90 mins
- Maximum accuracy was only 85%
- Discovered that additional duties were not in the data file:



- Conducted additional runs with longer “commute” times to account for consistent pre- and post-flight duties.



# Harmonized Parameter Test Settings

Parameter	Run 1 & 2 Settings	Run 3 & 4 Settings
Bedtime	22:00, 22:30, 23:00, 23:30, 00:00, 00:30, 01:00, 01:30, 02:00, 02:30	23:30
Max Rest Day Sleep	420, 450, 480, 510, 540 min	420, 450, 480, 510, 540 min
Max Work Day Sleep	390, 420, 450, 480, min	390, 420, 450, 480, min
Awake Zone Start	11:00, 12:00, 13:00	11:00
Awake Zone End	18:00, 19:00, 20:00	20:00
AutoNap	[480,600]:90;[601,720]:120;180; [480,600]:60;[601,720]:90;120; [480,600]:45;[601,720]:60;90; [480,600]:0;[601,720]:0;0	Zero
Commute	60, 90 min	60, 90, 120, 150 180, 210, 240
Minimum Sleep	60 min	60 min
Maximum Recovery Nap	90, 120, 180, 210 min	90, 120, 180, 210 min
Inflight Sleep Percentage	none	none

← Extended Commute



# Best Match Settings and Results

Parameter	Default	Harmonizer Best
Bedtime	23:00	23:30
Max Rest Day Sleep	540 minutes	540 minutes
Max Work Day Sleep	480 minutes	480 minutes
Awake Zone Start	13:00	11:00
Awake Zone End	19:00	20:00
AutoNap	60, 90, 120	zero
Commute	60 minutes	210 minutes
Minimum Sleep	60 minutes	60 minutes
Maximum Recovery Nap	210 minutes	120-210 same
Inflight Sleep Percentage	none	none

Run	Agreement Grand Mean	Agreement Total Sleep	Average Score
<b>Best Fit</b>	<b>88.6%</b>	<b>99.94%</b>	<b>94.24%</b>

Dramatic improvement in AutoSleep accuracy from 85% to nearly 89% with longer transition time validates the logic of the Harmonizer.

Typical Transition (“commute”) was 3.5 hrs

The Harmonized settings are very close to the default settings. With default settings and long commute time, accuracy is 88% and sleep/day is 99% correct





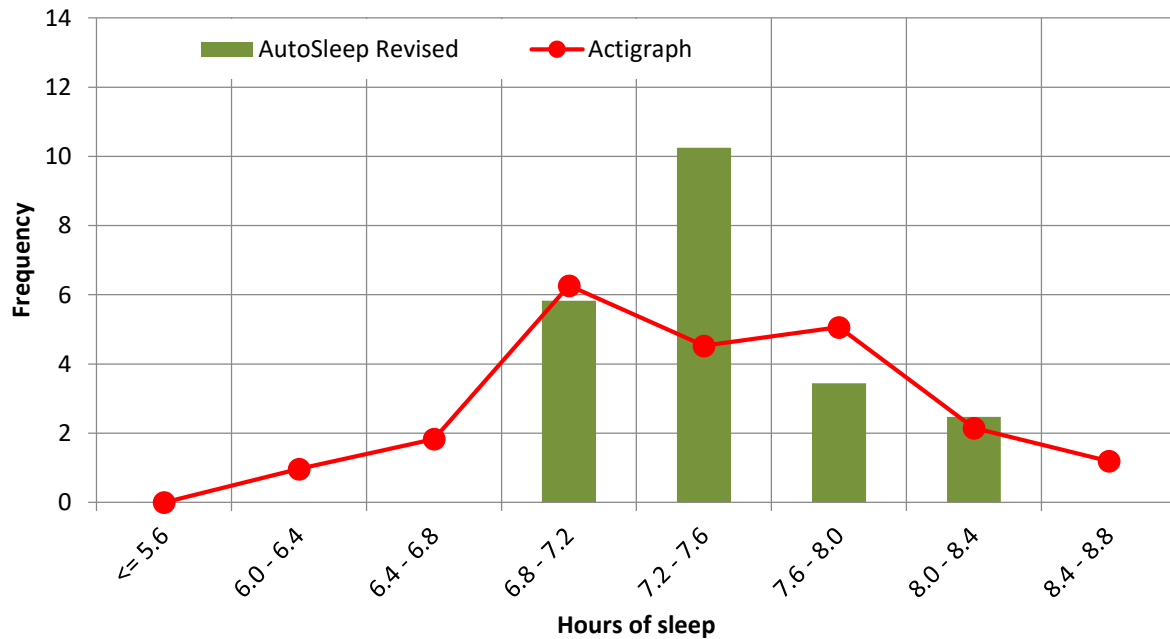
# Best Overall

*Red Line-Actual, Blue Bars-Default, Green Bars-Best Estimate*

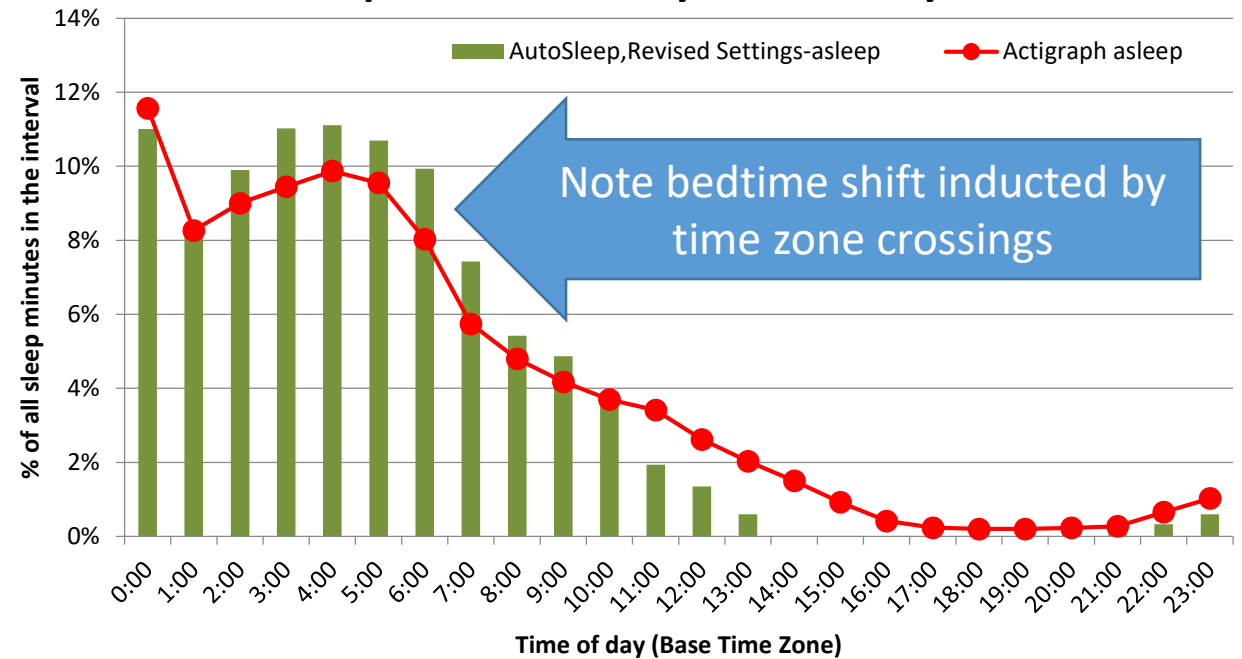
99.94 % Accurate for Overall Average Sleep per Day

88.6 % Accurate for Correctly Identifying Sleep Minutes

### Hours of Sleep per 24 hours

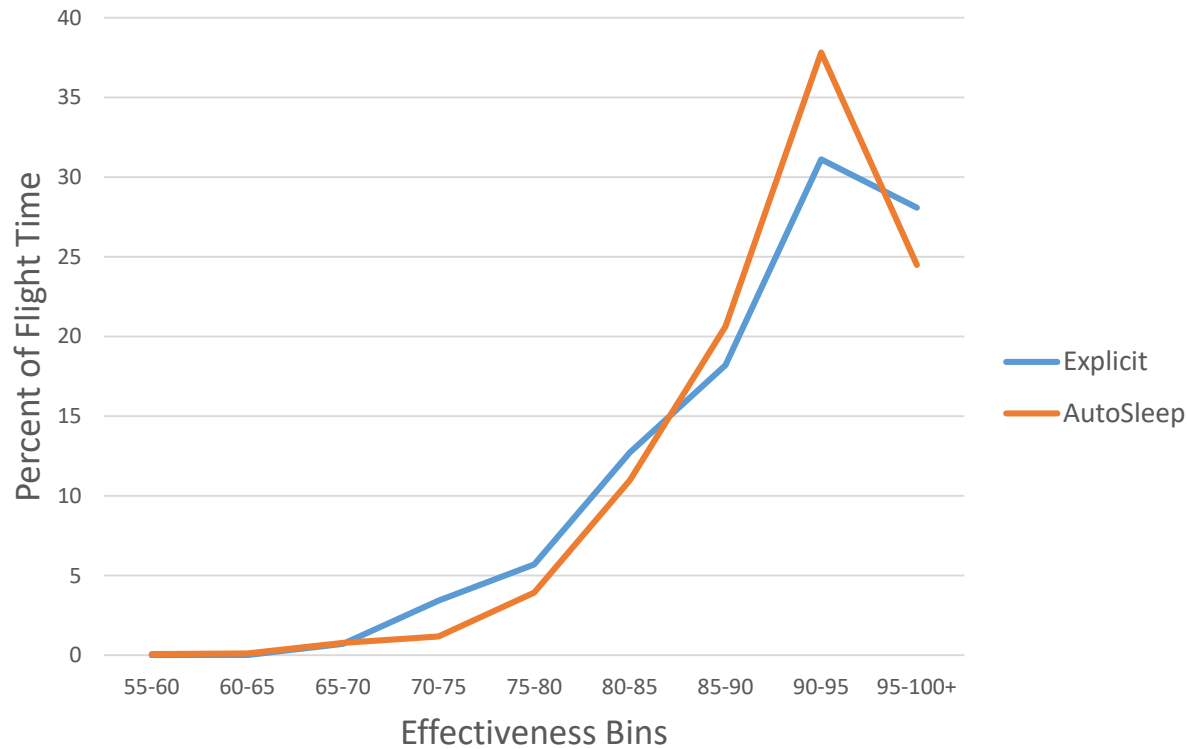


### Sleep Distribution by Time of Day

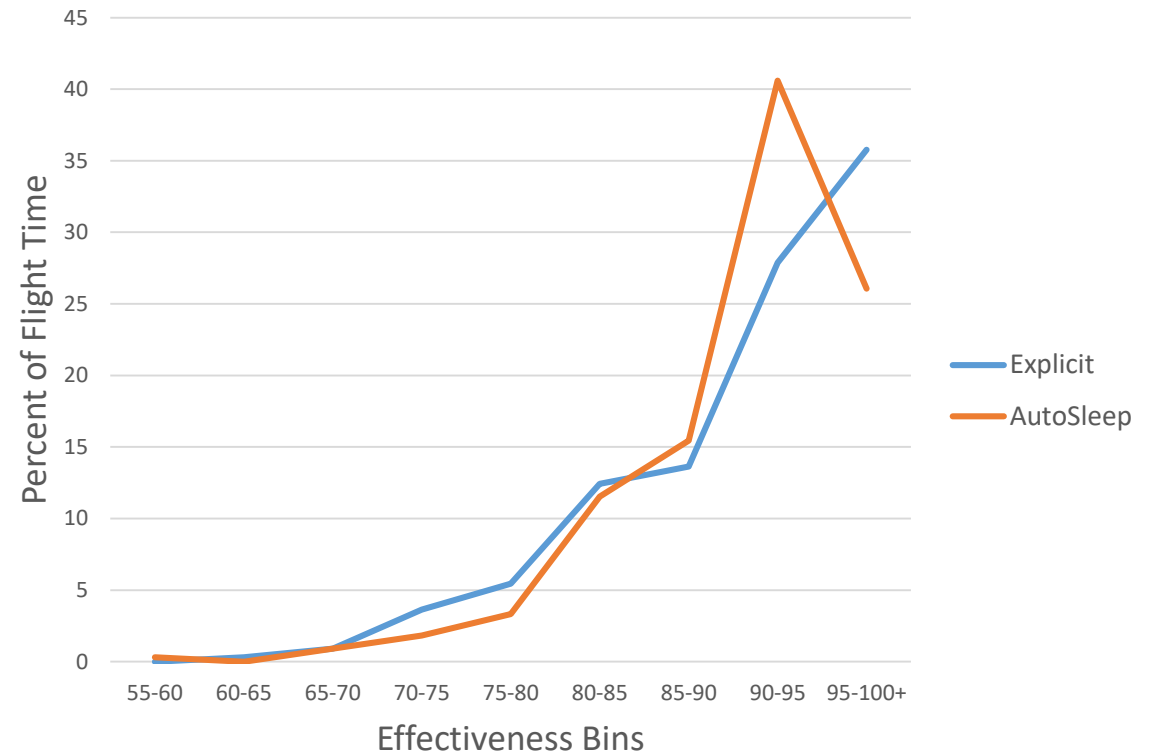


# Effectiveness Profiles

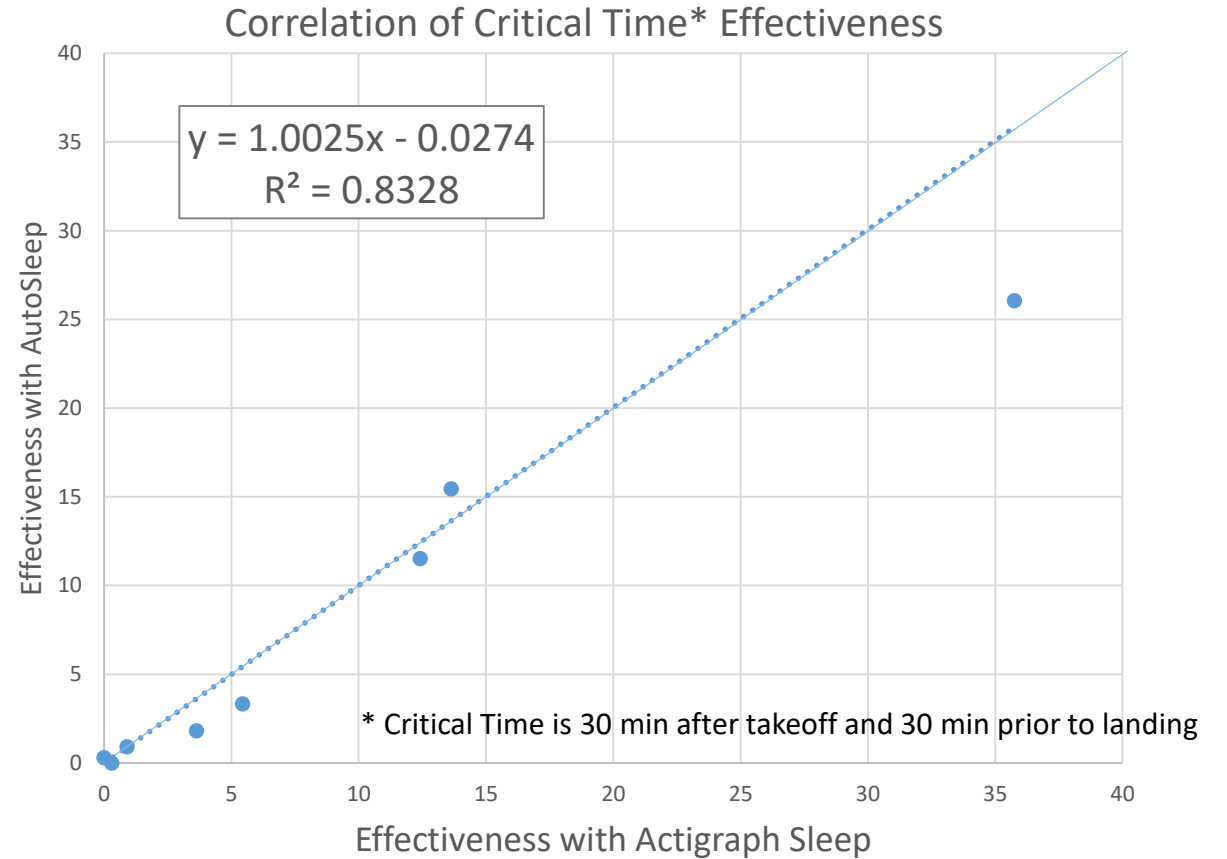
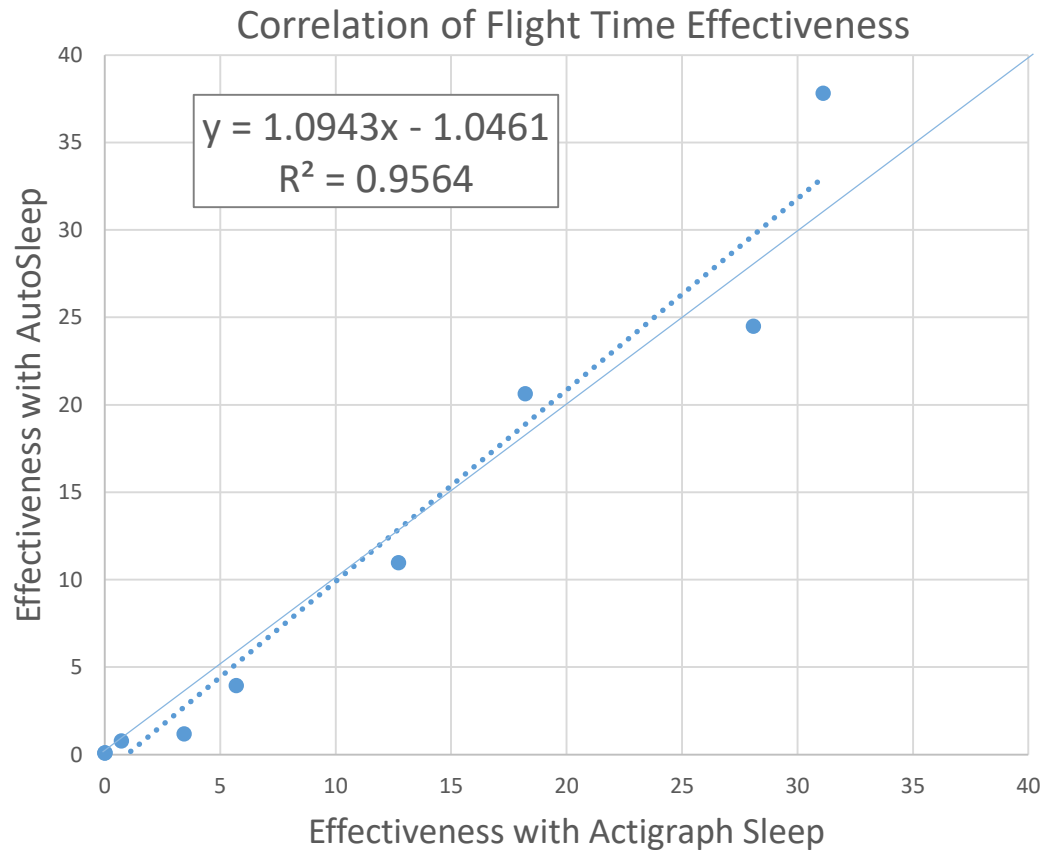
### Flight Time Effectiveness



### Critical Time Effectiveness

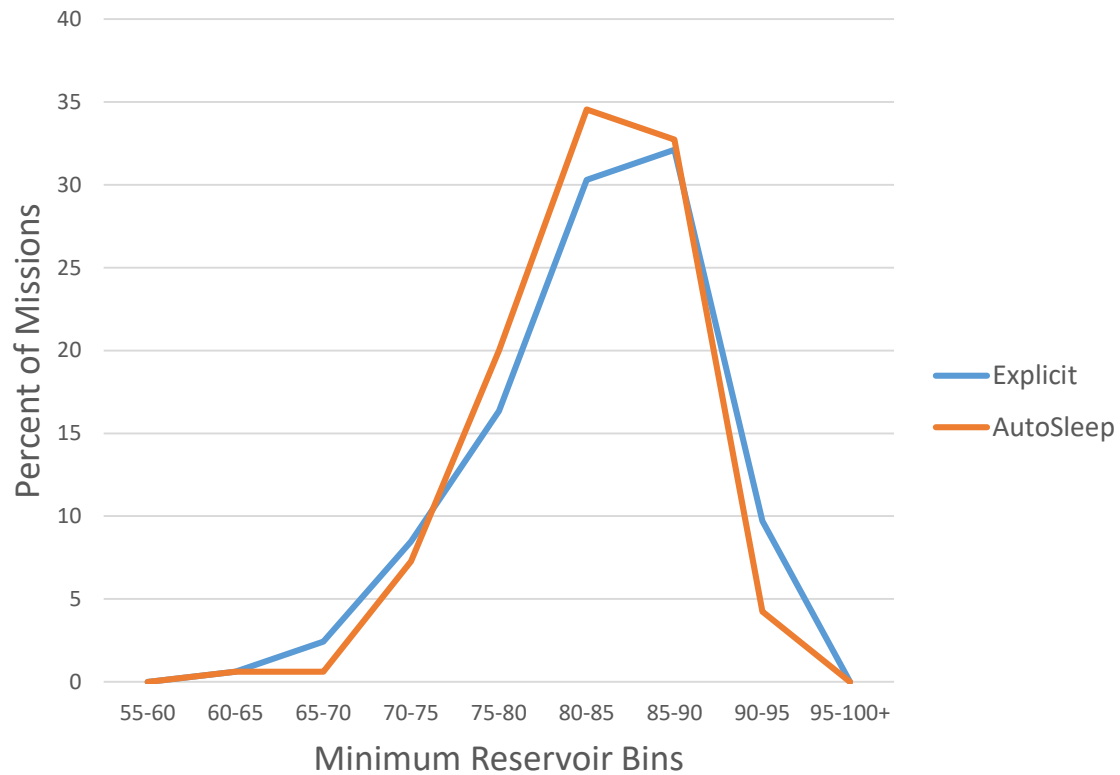


# Effectiveness from AutoSleep Highly Correlated to Actigraph

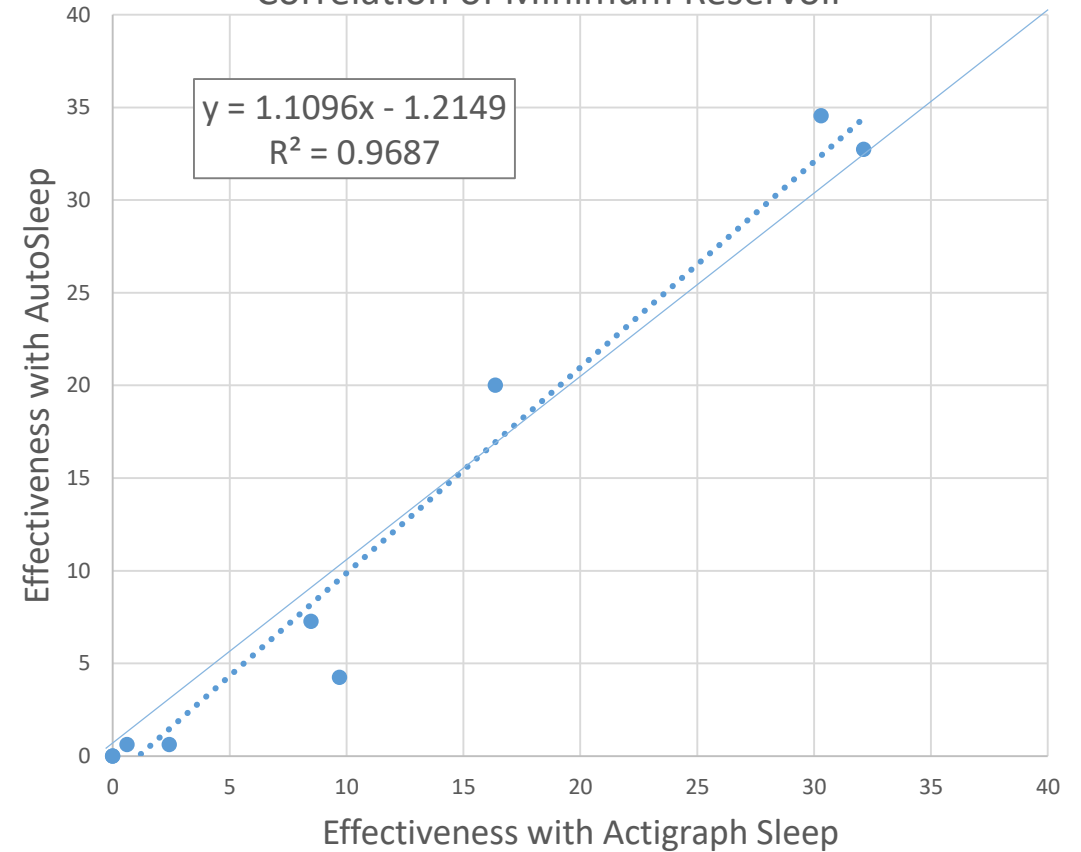


# Minimum Sleep Reservoir

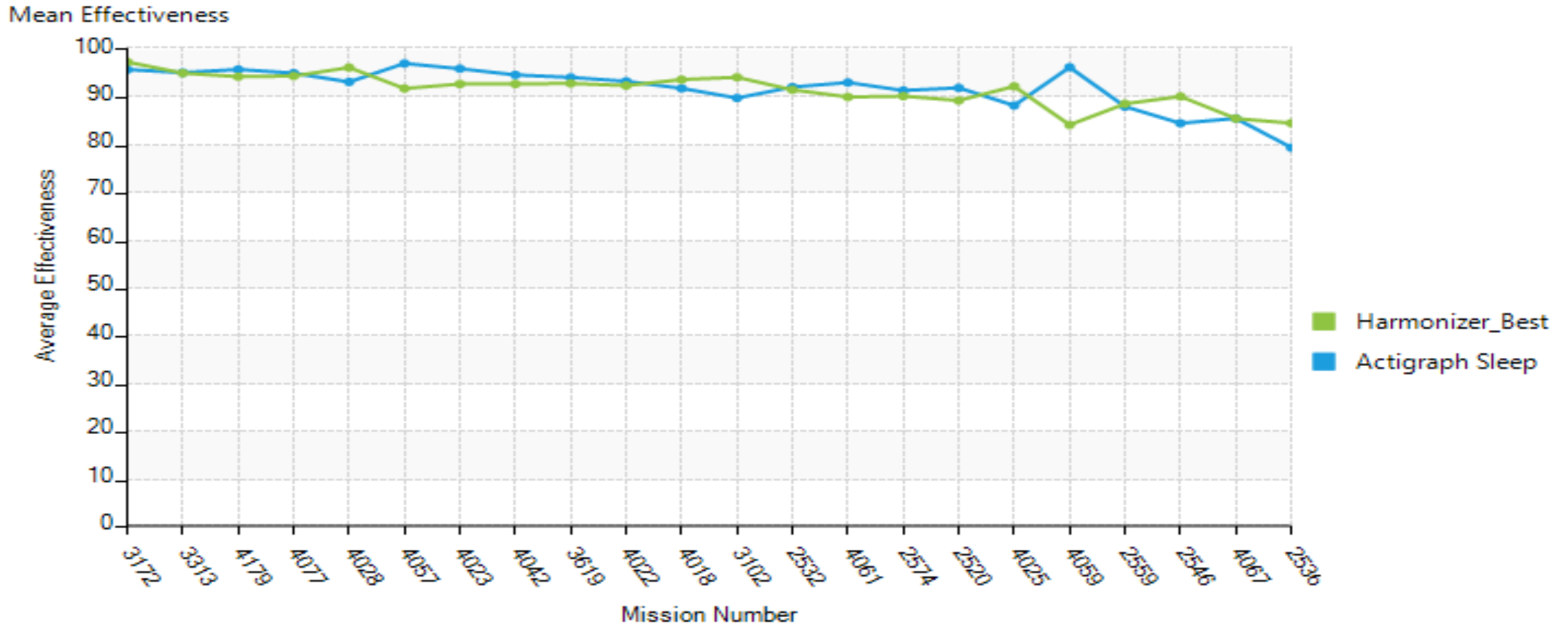
Minimum Sleep Reservoir Profile



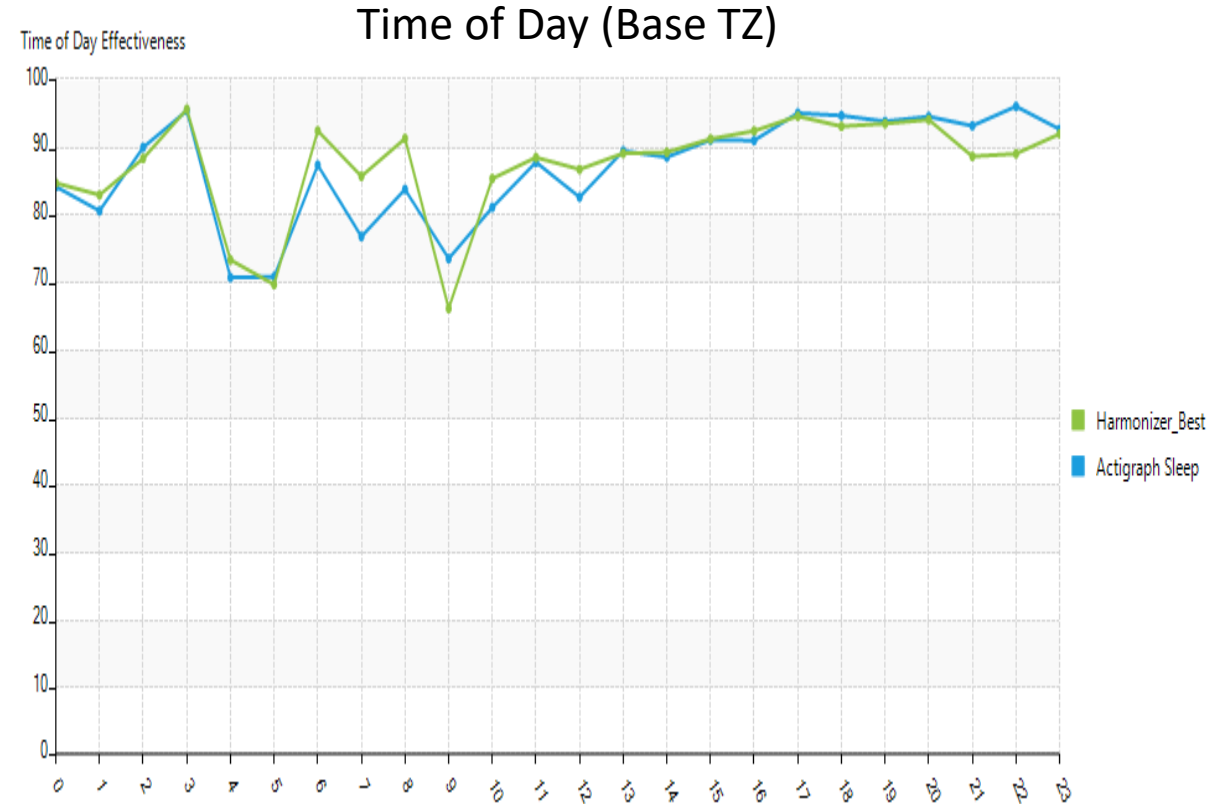
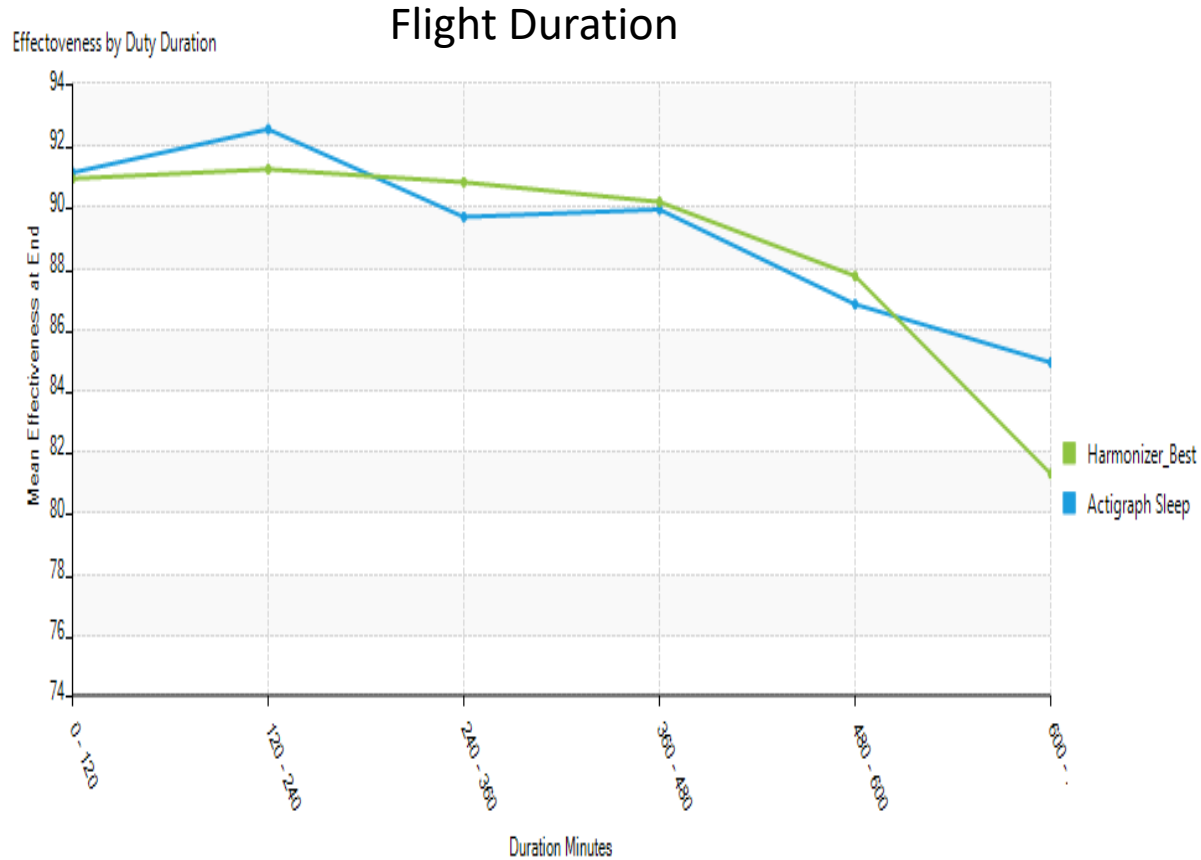
Correlation of Minimum Reservoir



# Mean Effectiveness by Mission



# Effectiveness at Arrival



# Conclusions for Military Study

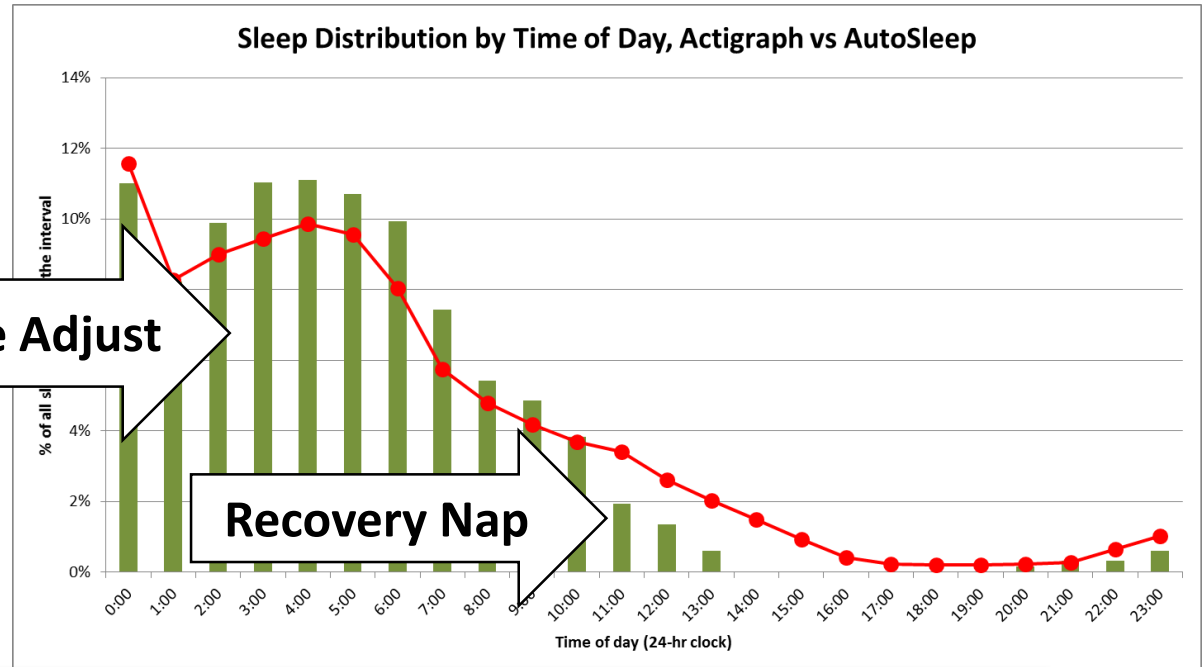
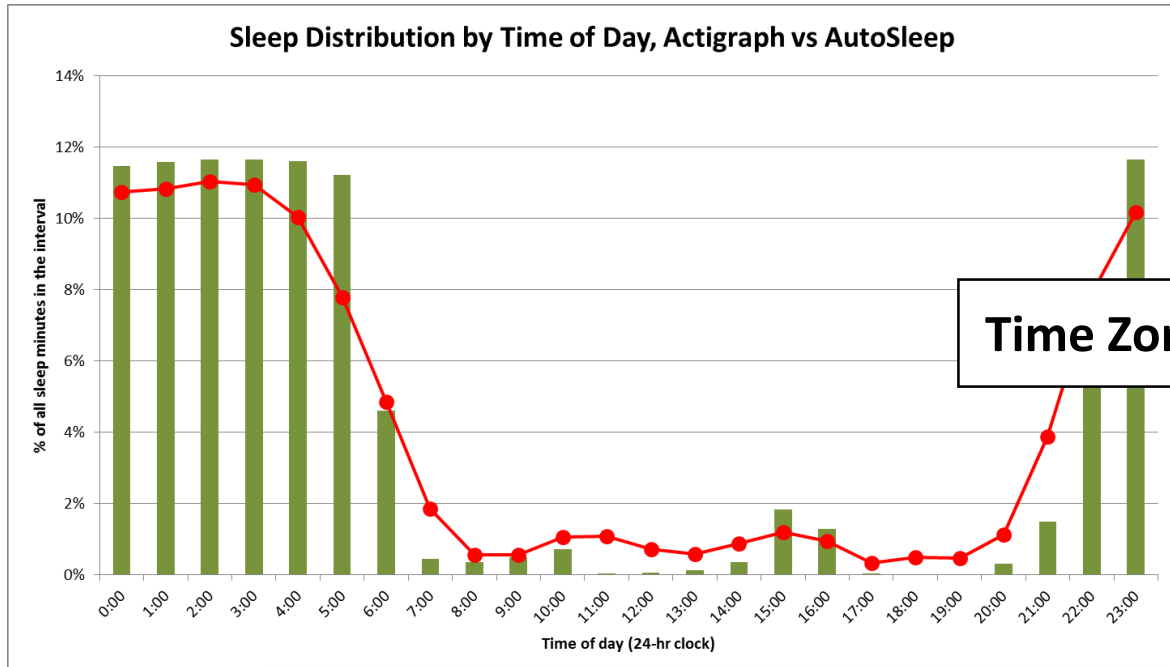
- Longer commute times greatly improved accuracy of AutoSleep; the “Best” case uses an average commute time of 3.5 hrs
- AutoSleep now matches actigraph sleep debt.
- Circadian pattern of effectiveness was virtually identical across Actigraph and AutoSleep.
- Effectiveness and fatigue risk based on AutoSleep is near perfect match to estimates based on actual sleep.
- Maximum values for work day and rest day sleep match the default settings in commercial aviation.



# Civilian vs Military Comparison: *Contrast of Time Zone Shifts*

Up to Three Time Zones

Up to Ten Time Zones



**Note: AutoSleep automatically tracks time zone changes and was not adjusted by the harmonizer.**





# Comparison of Parameters Values

Parameter	Harmonized Civilian	Harmonized Military
Bedtime	22:30	23:30
Max Rest Day Sleep	480 min	540 min
Max Work Day Sleep	450 min	480 min
Awake Zone Start	11:00	11:00
Awake Zone End	19:00	20:00
Commute	90 min	210 min
Maximum Recovery Nap	120 min	120-210 same
Inflight Sleep Percentage	60% of time	None
Min by Min Sleep/Wake Accuracy	88.26%	88.6%
Total Daily Sleep Accuracy	99.97%	99.94%



# Summary

- The Harmonizer found parameters of AutoSleep that closely matched the patterns and amounts of sleep in actual aviation operations.
- Patterns of sleep were quite different in the two studies, probably due to differences in time zone patterns.
- AutoSleep automatically tracks sleep across multiple time zones and was not adjusted during harmonization.
- Accuracy after harmonization was nearly 89% and average sleep per day was accurate to 4-6 minutes per day on average.



# Individualized Sleep Assumptions

- AutoSleep parameters can be set globally or for individuals
- Harmonize AutoSleep to individual subjects - Examples:
  - Commute time based postal code – one airline does this now
  - Preferred bedtime: Chronotype - “morningness” & “eveningness”
  - Nap durations: napping preferences vary individually





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# Conclusion of Presentation

[www.saftefast.com](http://www.saftefast.com)

# Distribution of Sleep Event Durations

*About a Quarter of Sleep Events > 8 hrs – Max Rest Day Sleep*

