# VALIDATING AND VERIFYING BIOMATHEMATICAL MODELS OF HUMAN FATIGUE

**Siera Brooke Martinez[1*], Luis Ortiz Quintero[2*], Erin Flynn-Evans, Ph.D.**
Fatigue Countermeasures Group, Human Systems Integration Division, Code TH

[1]siera.b.martinez@gmail.com, Undergraduate, University of Pennsylvania, Biology, NSBRI
[2]luisaortizquintero@student.hartnell.edu, Undergraduate, Hartnell College, Mathematics, NASA VIP
*These authors contributed equally to this project.

## I. ABSTRACT

- Airline pilots experience acute and chronic sleep deprivation, varying sleep inertia, and circadian desynchrony due to the need to schedule flight operations around the clock (Czeisler et al., 2007).
- Biomathematical fatigue models (McCauley Model, Harvard's Matlab Model, and the privately-sold SAFTE-FAST Model) have been useful in predicting pilot performance (Van Dongen, 2011).
- We compared model outputs to a pilot airline dataset of alertness and performance to find their strengths and weaknesses.
- Our findings will aid operational decision-makers in determining the reliability of each model under real-world scheduling situations.

## II. INTRODUCTION

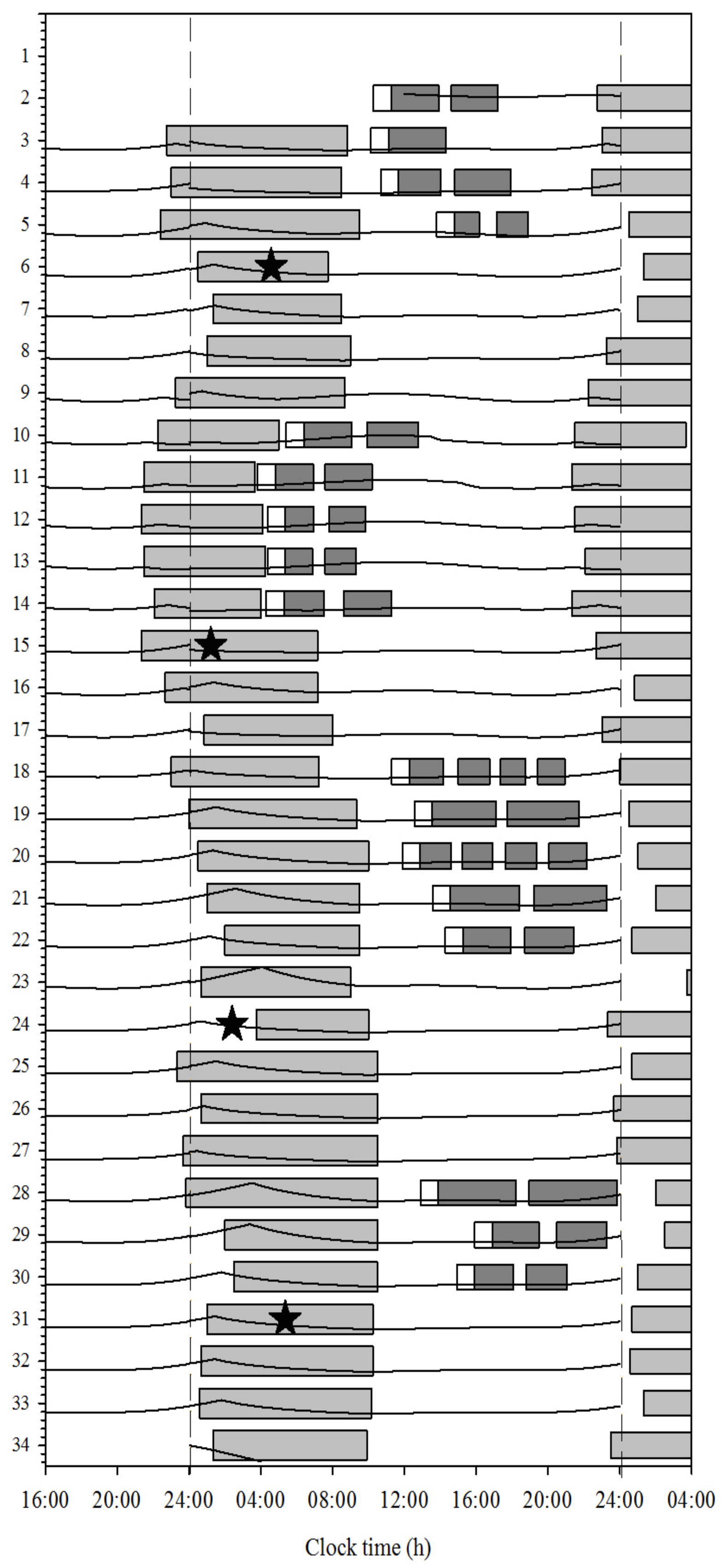
- Sleep loss and circadian desynchrony lead to cognitive impairments, reduced vigilance and inconsistent performance (Czeisler et al., 2007).
- Several biomathematical models, based principally on patterns observed in circadian rhythms and homeostatic drive, have been developed to predict a pilot's levels of fatigue or alertness. These models inform the Federal Aviation Administration (FAA) and commercial airlines of pilot capabilities and flight schedules (Mallis et al., 2004).
- These models have not yet been thoroughly tested in operational environments where uncontrolled factors, such as environmental sleep disrupters, caffeine use, and napping, may impact actual pilot alertness and performance.

| MODEL – TO PREDICT PERFORMANCE | INPUTS | OUTPUT (Performance) |
|---|---|---|
| McCauley Model | Day, sleep/wake state (binary), time | Estimated number of PVT lapses |
| Harvard University's Matlab Model | Time, sleep/wake state (binary), light (lux) | Cognitive Throughput (values between 0 and 1), where 0 equals the worst performance and 1 equals the best performance |
| SAFTE-FAST (private) | Sleep and flight schedules | Cognitive performance |
| **STANDARD – RECORDED PERFORMANCE** | **TEST** | **RESULT** |
| Pilot alertness and performance data | Psychomotor Vigilance Test (PVT) | Reaction time and number of times reaction time was >500ms (lapses) |

## III. METHODS

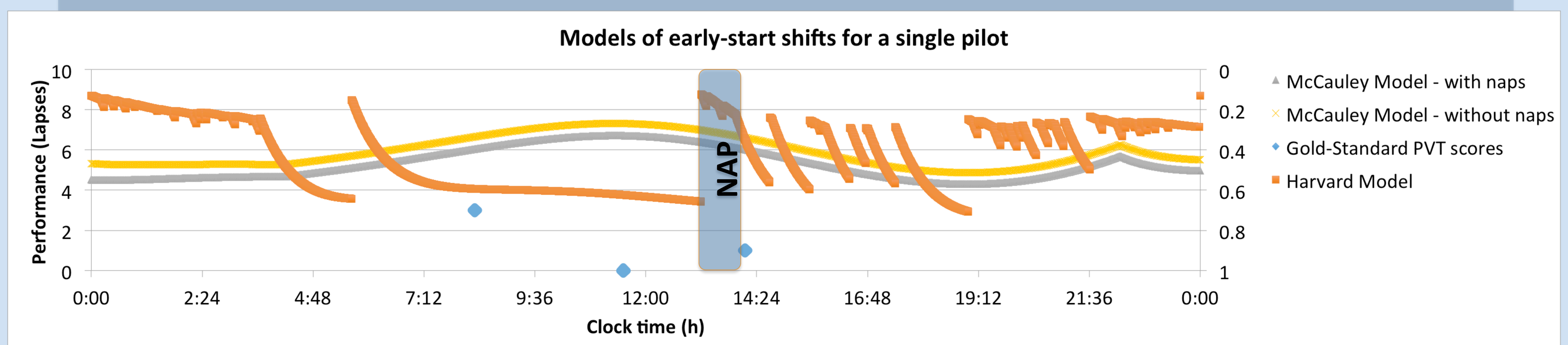
- The dataset used was previously collected from 44 pilots during normal schedule operations in a short-haul commercial airline over a period of one month and contained sleep logs, movement and light recordings, **psychomotor vigilance task (PVT),** and urinary melatonin (a marker of circadian phase).
- Pilots flew to a fixed pattern design (FPD) roster schedule, so there were several days of early, mid and late start days (see right).
- We preprocessed the dataset several times to serve as inputs for the three biomathematical models. In the McCauley Model, we did this with and without naps.
- PVT is the gold-standard measure of sleep deprivation-related performance impairment. This task measures the speed with which subjects respond to a visual stimulus and the number of times the subjects fail to respond to the appearance of the stimulus within 500ms. The PVT consists of responding to a small stimulus on the computer screen by pressing a response button as soon as the stimulus appears, which stops the stimulus counter and displays the reaction time (RT) in milliseconds.
  -Validated PVT response time is displayed accurately through devices by scoring a video experiment of PVT tests.

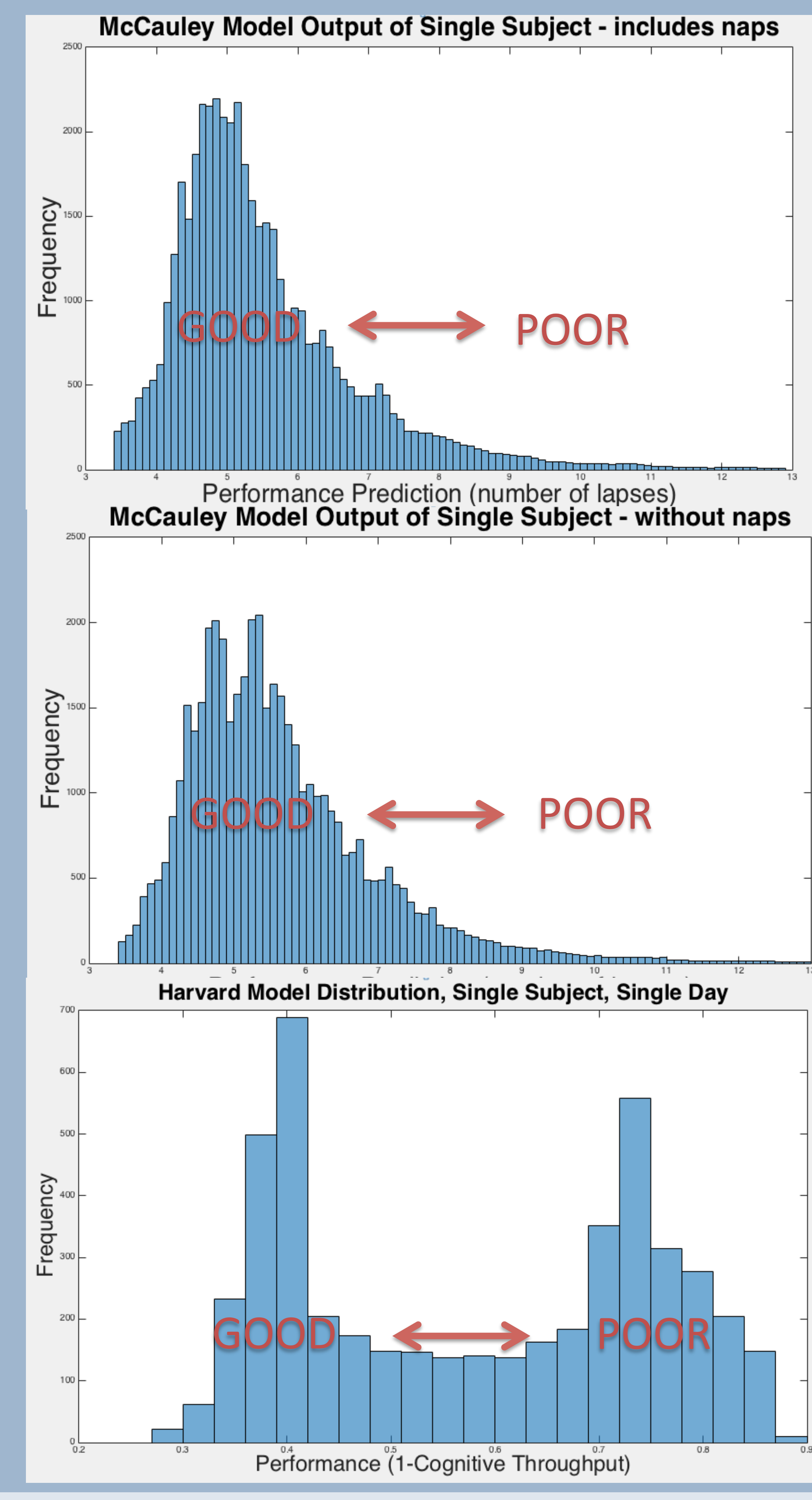
**Pilot Sleep and Flight Schedule with McCauley Model prediction**




## IV. ANALYSIS/DISCUSSION

- Statistically compared the values of performance that were either outputs from the three models or recorded from the PVT itself during the pilot data collection process for early, midday, and late shifts
- Calculated sensitivity and specificity of each model prediction
- Observed accurate shift when including nap input for McCauley Model




*The histograms above show the frequency of PVT score predictions with the McCauley Model (with and without naps) and the Harvard Model Cognitive Throughput for a single subject and day.*

## ACKNOWLEDGEMENTS

We would like to thank our PI, Erin Flynn-Evans, for the fascinating introduction into the field of sleep. With her enthusiasm and encyclopedic knowledge of this field, we were able to learn a great amount under her guidance this summer. We would also like to thank everyone in the Fatigue Lab, Chris Maese, NSBRI, and NASA VIP for making this project possible.

This investigation was sponsored in part by the National Biomedical Research Institute through NASA NCC 9-58.

## REFERENCES

Czeisler, C. A. and J. J. Gooley (2007), "Sleep and circadian rhythms in humans," Cold Spring Harb Symp Quant Biol, 72 579-97.
Mallis, M. M., S. Mejdal, T. T. Nguyen, and D. F. Dinges (2004), "Summary of the key features of seven biomathematical models of human fatigue and performance," Aviation, Space, and Environmental Medicine, 75(3 Suppl) A4-14.
Predicting cognitive impairment and accident risk. Thomas G. Raslear, Steven R. Hursh and Hans P. A. Van Dongen. H. P. A. Van Dongen & G. A. Kerkhof (Eds.) Progress in Brain Research, Vol. 190; 2011.