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CIRCADIAN ENTRAINMENT IN MILITARY PILOTS: TRANSITIONING FROM DAY TO NIGHT FLIGHTS

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MONTEREY, CALIFORNIA

THESIS

CIRCADIAN ENTRAINMENT IN MILITARY PILOTS: TRANSITIONING FROM DAY TO NIGHT FLIGHTS

by

James S. Reily

June 2022

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Second Reader: Panagiotis Matsangas

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13. ABSTRACT (maximum 200 words)

This study assessed the effectiveness of light exposure in transitioning aviation schedules from days to nights. We hypothesized that a single night of light treatment will delay melatonin onset and improve performance in a simulated flight task. Study participants were military pilots who flew four simulated flights: one baseline daytime flight and three consecutive night flights. Pilots were exposed to four hours of high energy visible (HEV) light (1,000 lux) on the second night but remained in dim light on the first and third nights. Saliva samples for determining melatonin levels were collected every half hour during the three nighttime data collections. Participants also completed questionnaires to include the Bedford Workload Scale and the Karolinska Sleepiness Scale. We tracked each participant's circadian rhythm using their melatonin onset profiles over the three nights of the study. Pilot performance in a flight simulator was assessed for each of the three data collection sessions using three flight profiles of progressing difficulty. Results showed an average delay in melatonin onset mean of 1.33 hr (SD = .36 hr). Flight performance over the testing period did not show any significant changes. This study showed that light can be used to effectively delay the onset of melatonin, potentially providing a substantive advantage to personnel who must rapidly transition to new work schedules. Further study is recommended before implementing in operational conditions.

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CIRCADIAN ENTRAINMENT IN MILITARY PILOTS: TRANSITIONING FROM DAY TO NIGHT FLIGHTS

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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LIST OF ACRONYMS AND ABBREVIATIONS

ANAM	Automated Neuropsychological Metrics
AvORM	Aviation Operational Risk Management
BWSI	Bedford Workload Scale Index
CDI	Course Deviation/Glideslope Indicator
CPS	Circadian Positioning Systems
DLMO	Dim Light Melatonin Onset
DOD	Department of Defense
ESS	Epworth Sleepiness Scale
F/A-18	Fighter/Attach Jet Aircraft
IAS	Indicated Airspeed
ILS	Instrument Landing System
HEV	High Energy Visible
KC-130	Aerial Tanker Aircraft
KSS	Karolinska Sleepiness Scale
LTJG	Lieutenant Junior Grade
NATOPS	Naval Aviation Training and Operating Procedures Standards
NPS	Naval Postgraduate School
PSQI	Pittsburgh Sleep Quality Index
PVT	Psychomotor Vigilance Task
REM	Rapid Eye Movement
SCN	Suprachiasmatic Nerve
SOP	Standard Operating Procedures
USCG	U.S. Coast Guard

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EXECUTIVE SUMMARY

Fatigue is a problem for military aviation. A high rate of military aviation mishaps have fatigue as a causal or contributing factor. The tools and policies for fatigue mitigation in the military do not address fatigue resulting from misaligned circadian rhythms. This study tested a method to counteract fatigue using light to quickly shift circadian rhythms. This method has the potential to help pilots transition more quickly from day to night flights and to stay more alert during night flights, thereby reducing fatigue-related mishaps.

Researchers recruited ten participants with prior aviation experience from among Naval Postgraduate School (NPS) students and faculty. Both males and females from a mixture of service branches and aviation backgrounds participated. All were previously qualified to conduct the procedures in the simulated flight. One participant was excluded from the study due to abnormally high melatonin levels.

After becoming familiar with the simulator, participants flew one baseline flight during the day, followed by simulated flights on three consecutive nights. On the second night, they were exposed to 1,000 lux light. Researchers then compared participants' melatonin levels and flight performance from the daytime session, pretreatment night, and post-treatment night. Our hypothesis was that a single night of light treatment will delay melatonin onset and improve pilot nighttime performance. We predicted our results to show that compared to baseline performance for the day flight, performance on the first night flight would be reduced. We also predicted that compared to values on the first night, performance on the third night would be better and melatonin onset will be delayed.

We saw a delay in melatonin onset indicating a phase delay in participants' circadian rhythms. On average, melatonin was delayed by 1.33 hours on the third night of the study compared to the first night. Researchers did not see major changes in performance. The absence of performance changes could be due to any of the following limitations in the study. The sample size was small due to the specific skillset needed for the experiment and because the study was conducted at the beginning of the COVID-19 pandemic. The scenarios may not have been challenging enough for the skill level of many

of the participants. Additionally, the factors chosen to measure performance may not have been the most sensitive for measuring changes in mental alertness.

Melatonin assays for all participants indicated a significant shift in their circadian rhythms after the light treatment, an approximately 5-fold increase over what would be expected without light exposure. Results showed an average delay in melatonin onset mean of 1.33 hr (SD = .36 hr). We analyzed the performance in the simulator as planned but did not find significant changes in the way that we expected. However, we did identify certain aspects of performance that could be tracked in future studies to better indicate fatigue. This study showed that light can be used to effectively delay the onset of melatonin, potentially providing a substantive advantage to personnel who must rapidly transition to new work schedules. Further study is recommended before implementing in operational conditions.

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I have so many people to thank for getting this thesis complete. First, I would like to thank everyone who helped with data gathering starting with: LTJG Meghan McDonough for being an excellent lab partner; Katy Giles (CDR, USN) and Dr. Matt Taranto (Lt.Col., USAF) for their expertise in the simulator and all things aviation; Dr. Eliza Van Reen for her expertise on light and sleep; Marina Lesse, Michelle Hancock, and Dr. Heather Clifton for keeping the lab running smoothly and volunteering to take those late data collection shifts. I also want to thank the participants for sacrificing their time for a good cause.

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I. INTRODUCTION

A. BACKGROUND

On December 6 of 2018, six Marine Corps aircrew members lost their lives during a training accident. The mishap investigation revealed fatigue as a major contributing factor, as have several other post-accident investigations. A recent study conducted by the Naval Safety Center found that fatigue and fatigue-related stressors were contributing factors in 20% of naval aviation accidents, ultimately costing the government $842M from 2015 to 2019 (Durning & Kelly, 2020). Policies established by the military for crew rest aim to mitigate fatigue resulting from long work hours (Department of the Navy, 2017). Currently, a pilot's maximum number of consecutive flight hours without rest is tightly regulated, and pilots must have a certain amount of time off before a flight (DON, 2017). However, having the requisite hours off before a flight does not necessarily mitigate the risk of aviator fatigue, especially when a pilot's biological regulation of sleep and wake is not aligned with their schedule. While many circumstances allow for a gradual adaptation to a different schedule (e.g., when there are several days off before switching to a new schedule), the operational pace in military aviation results in pilots needing to shift schedules quickly. A pilot's biological clock cannot immediately adapt when switching to a new schedule, even with the approved crew rest hours prescribed by flight manuals (Caldwell, 2009). For pilots shifting to night schedules or those changing time zones, this "lagging" leaves them particularly vulnerable to fatigue while flying which increases the risk of mishaps.

The processes within the human body that influence when humans are predisposed to sleep and wakefulness are the homeostatic and circadian processes (Gandhi, 2015). The homeostatic process is the pressure to sleep that increases in intensity over hours awake. The circadian process is the cyclic control that keeps its own time separate from a person's behavior, reflecting the activity of the biological pacemaker with rhythmicity approximately equal to the length of a 24-hour day (Borbély, 1982). The body receives external cues such as light that help keep it in step with the environment. These external cues are called *zeitgebers* and they can influence the circadian process by pushing it to the right or left, or by further stabilizing an established rhythm. This shifting of the circadian process to align it with a sleep/wake schedule is known as circadian entrainment (Waterhouse et al., 2004).

The process of circadian entrainment takes place whenever a new schedule is adopted or time zones shift. Before the body is fully entrained, there is a period in which the circadian rhythm is mismatched with sleep/wake behavior. This mismatch between behavior and the circadian clock is called circadian misalignment. Circadian misalignment is often characterized by attempting to sleep when the body is promoting wakefulness and being awake when the body is promoting sleepiness. Social and work pressures may produce circadian misalignment, which has been shown to be a major contributor to chronic fatigue and the associated degraded performance among operators (Gold et al. 1992). Additionally, circadian misalignment is associated with both short- and long-term negative health effects and can detrimentally influence cognitive performance (Ingram, 2020; Guo et al., 2020).

Naval leadership has recognized that sleep is important for ensuring optimal operator performance. On the surface, this recognition can be seen in the recent policy changes regarding watch schedules that allow for adequate rest and align with a 24-hour clock. However, the unpredictability of mission demands and irregular operational tempos do not allow for a consistent schedule. The result is that Navy and Marine Corps pilots are often forced to operate under circadian misalignment, which contributes to an increased risk for mishaps to occur. Current guidelines on crew rest in military publications address the issue of fatigue produced by extended hours awake (homeostatic process), but they devote less attention to the issues resulting from the disruption or misalignment of the biological regulation of sleep and wake (circadian process). This study aims to contribute to efforts to develop methods for mitigating risk caused by circadian misalignment.

B. STUDY AIM AND OBJECTIVES

The overarching aim of this study was to assess whether strategically exposing aviators to high-energy visible (HEV) light will reduce the time needed to adapt to night flights. The specific questions this thesis sought to answer were the following:

Does the strategic light treatment shift the circadian clock? We answered this question by assessing the melatonin onset of the participants for their three nights in the laboratory.

Does strategic light treatment improve nighttime flight performance? We measured nighttime flight performance using a realistic flight simulator and augmented these performance measurements for some of the participants by measuring vigilant attention.

We hypothesized that a single night of HEV light treatment would delay the onset of melatonin in participants, which would reflect a delay in their circadian rhythms. We also hypothesized that pilot nighttime performance after the HEV light treatment would be better than nighttime performance on the baseline night before the light treatment.

The data collected for this study was gathered by a team of researchers including Lieutenant Junior Grade (LTJG) Meghan McDonough, whose thesis focused primarily on the physiological outcomes (i.e., the melatonin levels of the participants), whereas this thesis focuses primarily on the aviation performance and cognitive performance.

C. THESIS OUTLINE

This thesis includes six chapters. The first chapter is an introduction and overview of the main aim of the thesis. The second chapter reviews pertinent research on this topic. The third chapter details the research methods and practical steps employed to obtain the data. The fourth chapter covers the results obtained from this experiment. The fifth chapter expounds on the interpretation of the results and discusses implications for Navy and Marine Corps flight operations. The final chapter suggests potential areas for follow-up research.

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II. LITERATURE REVIEW

On December 6, 2018, a mid-air collision between an F/A-18 and a KC-130 occurred after conducting night refueling operations. The Assistant Commandant of the Marine Corps outlined the factors that caused the mishap. The first causal factor was that the flight lead for the group of F/A-18s requested a non-standard departure to the left side of the KC-130. The flight lead had also turned on a brighter than usual lighting configuration, leading the mishap F/A-18 pilot to focus on the flight lead and lose sight of the KC-130. This distraction caused the F/A-18 to inadvertently drift to the right and into the tail of the KC-130, ultimately causing both planes to enter unrecoverable flight profiles. These issues contributed directly to the mishap, but the Commandant also highlighted secondary factors at the institutional level that contributed indirectly to the mishap. From these secondary factors, the Commandant called out the need for recommendations concerning "manning, training, operations, and medical policies" (Thomas, 2020, p. 2). These recommendations include a request for review of naval publications concerning fatigue and research, specifically focused on the role of fatigue in mishaps. These recommendations provided the impetus for the research that was conducted for this thesis.

A. WHAT IS FATIGUE?

For the purposes of this study, fatigue is defined as the perceived need for sleep and the cognitive impairment that accompanies it. However, multiple sources cited in this text approach fatigue from different points of view. Furthermore, the subjective feeling of fatigue can arise from different causes, including physical work, mental work, and time of day. Fatigue is often used as a "catch-all" term in many military publications that relates to all these different causes. Sleepiness or somnolence is a more specific aspect of the predisposition toward sleep and not just the need for rest (Neu et al., 2010). Herein lies the importance of establishing a clear definition of fatigue for this thesis. Many assume that fatigue can be mitigated instantaneously, with time away from work. However, these measures do not necessarily address the type of fatigue that is the focus of this thesis, the fatigue that is due to circadian misalignment.

The Naval Safety Center defines fatigue as "a condition characterized by a lessened capacity for work and reduced efficiency of accomplishment, usually accompanied by a feeling of weariness and tiredness. Fatigue can be acute and come on suddenly or be chronic and persistent" (Durning & Kelly, 2020, p. 1). This definition is appropriately broad and symptom-focused within the context of aircrews. It is used to evaluate aircrew physical condition during a mishap investigation. The naval medical community recognizes the complex nature of fatigue, even giving the fatigue chapter in their handbook the byline "Easy to understand but difficult to define" (NAVMED P-6410, 2000, p. 6). Thus, they are aware that the Naval Safety Center definition may not be as complete or thorough as it could or, perhaps, should be.

Researchers studying fatigue have struggled to develop a more precise definition that encompasses the psychological processes and causes behind fatigue, along with its nuanced effects and with an emphasis on performance. John and Lynn Caldwell, aviation physiologists and sleep and performance researchers, have focused on fatigue for over thirty years, and pose this definition: "Fatigue is the state of tiredness that is associated with long hours of work, prolonged periods without sleep, or the requirement to work at times that are 'out of synch' with the body's biological or circadian rhythms" (Caldwell & Caldwell, 2003, p. 15). The last part of this definition, "out of synch," is the focus of this paper, and arguably, should receive more attention within the aviation community.

B. BIOLOGICAL RHYTHMS

For this study, sleep has been defined as "a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment" (Jain & Glauser, 2014, p. 26). The average adult needs at least seven to nine hours of sleep a night for physical health (Hirshkowitz et al., 2015; Watson et al., 2015). Not getting the recommended amount of sleep over multiple nights, which produces a sleep debt, can result in deteriorated health, immunity, and decreased performance (Cohen et al., 2010).

To properly understand the fatigue that is caused by sleep debt, it is important to also understand the biological regulation of sleep and wakefulness. Two major biological processes dictate the biological regulation of sleep and wake cycles. The first process involves the amount of time an individual has been awake, called the homeostatic process. It represents the increasing need for sleep over the time a person is awake, and a decreasing need for sleep over time asleep (Borbély, 1982; Kryger et al., 2017). At a certain point, the propensity for sleep is high enough that sleep is initiated. While asleep, this same homeostat reaches a low point where the mechanism for waking is started. In this way, the biological regulation of sleep and wake is dynamic and responsive to sleep history.

The second process, the circadian process, is concurrent with the homeostatic process. It regulates sleep and wake behavior such that an individual feels awake in the morning and sleepy at night. The circadian process promotes sleepiness and alertness independent of how much sleep an individual had in the recent past (Munch et al., 2020). Circadian rhythms are observed in a wide variety of species from single-celled organisms to humans (Gandhi, 2015). Together, the homeostatic and circadian processes regulate the sleep-wake cycle (Borbély, 1982).

It is also important to understand the parts of the brain that control sleep. In the center of the brain, beneath the cortex, the hypothalamus controls some of the most essential biological functions, including functions regulated by the autonomic nervous system (e.g., breathing and heart rate). Within the hypothalamus is the suprachiasmatic nucleus (SCN). The primary input of the SCN is the neurons that receive light information at the retina. Light is the primary “time-giver” or *zeitgeber* for the SCN. The SCN acts as the conductor, or time indicator, for circadian rhythms. One of the major functions of the SCN is coordinating with the thalamus and the brain stem to transition brain functions to a sleep state. The thalamus filters and converts sensory information to the cerebral cortex, where more complex cognitive functions occur (e.g., decision making and risk management).

During sleep, the thalamus is mostly inactive. It does become active during rapid eye movement (REM) sleep. The brain stem limits the activity of the arousal centers entering sleep and sends signals to relax skeletal muscles to prevent physical movement during REM sleep. (National Institute of Neurological Disorders and Stroke, 2019). All these processes are endogenous, meaning they happen inside the body. They are related to levels of a specific hormone within the body- melatonin- that is manufactured by the pineal gland.

Melatonin acts as a chemical signal for the brain to transfer into a sleep state. It is produced by the pineal gland, which receives information from the SCN (Schwartz & Roth, 2008); see Figure 1. Melatonin plays a role in the regulation of circadian rhythms and the primary nocturnal sleep gate, a window of time in which the human body is most likely to fall asleep (Lavie, 1997). It is the rise in the concentration of melatonin in the body during this time that leads researchers to believe it is critical to circadian regulation. It is conspicuously absent in people who suffer from certain sleep disorders. These people have been treated successfully with synthetic melatonin, further confirming its role in the regulation of the circadian rhythm (Zisapel, 2018).

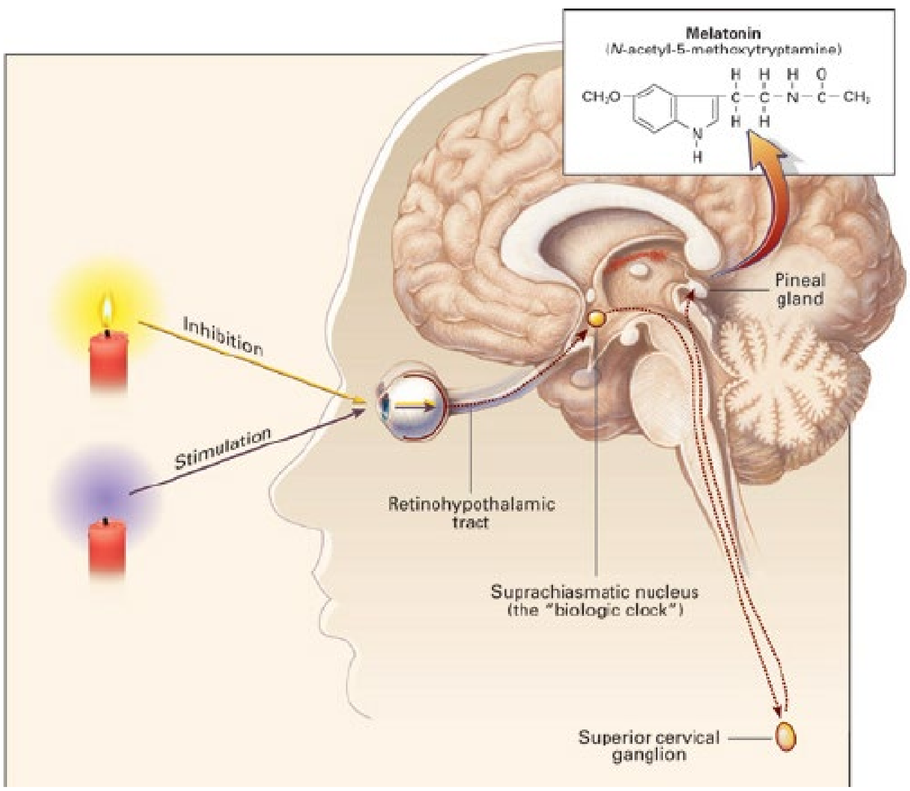

Figure 1. Internal Processes Related to Production of Melatonin. Source: Shirani & St Louis. (2009).

Researchers can track the cyclical rise and fall of melatonin concentrations within the body throughout a twenty-four-hour period (Ackerstedt et al., 1982). The rise in melatonin within the body is a marker used by researchers that is related to the circadian phase. The circadian phase is often estimated using a dim light melatonin onset (DLMO) protocol (Keijzer et al., 2014). Bright light suppresses melatonin secretion. Thus, researchers have been able to use bright light, strategically administered at certain times of the day, to shift a subject's DLMO earlier or later. This treatment can be administered to shift workers who need to work during times when they would normally be sleeping, thereby helping them remain alert (Stewart et al., 1995).

C. LIGHT AS A ZEITGEBER

Light frequency, intensity, and duration can be altered to achieve an optimal effect on the circadian rhythm, such as a shift in DLMO. Research into the frequency of light has shown how light is translated to signals in the brain, revealing that the best frequency responses correspond with the spectral sensitivity of the active pigment (melanopsin) in photosensitive retinal ganglion cells within the retina (Blume et al., 2019). Rod and cone cells may also affect the SCN. Rods specifically have been shown to have non-visual effects on brain function (Altimus et al. 2010).

The next property of light that can be modified to effectively shift circadian phase is light intensity. Over a broad range of disciplines, light intensity is measured in lux, with one lux corresponding with one lumen per square meter (Encyclopedia Britannica, n.d.). A lumen is a unit of perceived visual power within the spectrum of the human eye, which is extremely adaptive and can receive visual information under a broad range of light intensity conditions. For instance, the light level of a candle-lit room is usually no more than five to ten lux and the standard windowless office building is 100–200 lux, but a bright sunlit day can be as much as 25,000 lux in direct sunlight (Spitschan, 2016). For the past forty years, researchers have been testing the effects of various light intensities on circadian rhythms. Phillips and colleagues (2019) found large variations in sensitivity to lux levels among different persons, such that some individuals were sensitive to light as low as six lux while others were not sensitive to light that was up to 350 lux (Phillips, 2019).

Another group of researchers contends that levels of light as low as one lux can have an effect on the SCN and melatonin secretion (Walbeek et al., 2021). However, these findings must be balanced with the practical efforts that need to be undertaken to potentially implement these treatments. The design of the current study used a light intensity that can be reasonably achieved outside of lab conditions. Phipps-Nelson et al. found improvements in performance and alertness following a bright light treatment of 1000 lux for four hours in the morning and evening with dim light conditions of five lux maintained for the rest of the performance period. These conditions are easily repeatable, but their results require further study because Phipps-Nelson and colleagues (2003) did not see a major change in melatonin levels and did not measure participants the day after the treatment to see if the treatment's effects continued. The current study adapted this research to measure participants' performance in a setting that more closely simulated an operational environment, adding to the external validity of the treatment explored by this thesis.

The duration of light exposure can also be manipulated to alter circadian rhythms. In determining the variation in sensitivity to light, Phillips et al. (2019) conducted a light treatment regimen of five hours of daily bright light exposure during habitual bedtime that lasted one week. Duffy and colleagues (1996) conducted a 15-day study using core body temperature to measure circadian phase shifts and a five-hour treatment of bright light each day. This particular study had a control group that was kept in dim light as well. A Scandinavian research team also conducted a four-week-long bright light treatment for night shift workers with thirty-minute intervals of bright light interspersed throughout their eight-hour workday. These researchers documented a 4.9-hour shift in DLMO (Lammers-van der Holst et al., 2021). Crowley et al. (2003) entrained night shift workers over only four days using a combination of five bright light pulses (20 min) during waking periods while using light-blocking sunglasses during periods closer to sleep.

D. FATIGUE IN AVIATION

The effect of fatigue on higher cognitive functions has been measured in multiple studies. Burke et al. (2015) tested performance in relation to both the circadian phase and sleep inertia, the speed at which cognitive processes return to waking levels. They found that sleep-deprived participants experienced a decrease in inhibitory control and a decrease in visual attention. Both tasks are necessary for the safe operation of an aircraft. Belenky and colleagues (2002) studied performance as it related to hours slept per night. They found that performance dropped markedly for subjects who only slept three hours per night and did not recover even after three nights of normal sleep. Furthermore, even though their performance was degraded, these subjects believed they were performing at the same level as they had been at the start of the study.

This lower performance level leads to errors, specifically in the world of aviation. Fatigue is one of the primary contributing factors to mishaps in Naval Aviation shown in the chart below. This problem is further exacerbated by the general military culture regarding sleep. In 2018, the DOD Health Related Behaviors Survey estimated that 54.6% of military personnel failed to meet the Centers for Disease Control and Prevention criteria for sufficient sleep (Bergtholgt, 2021).

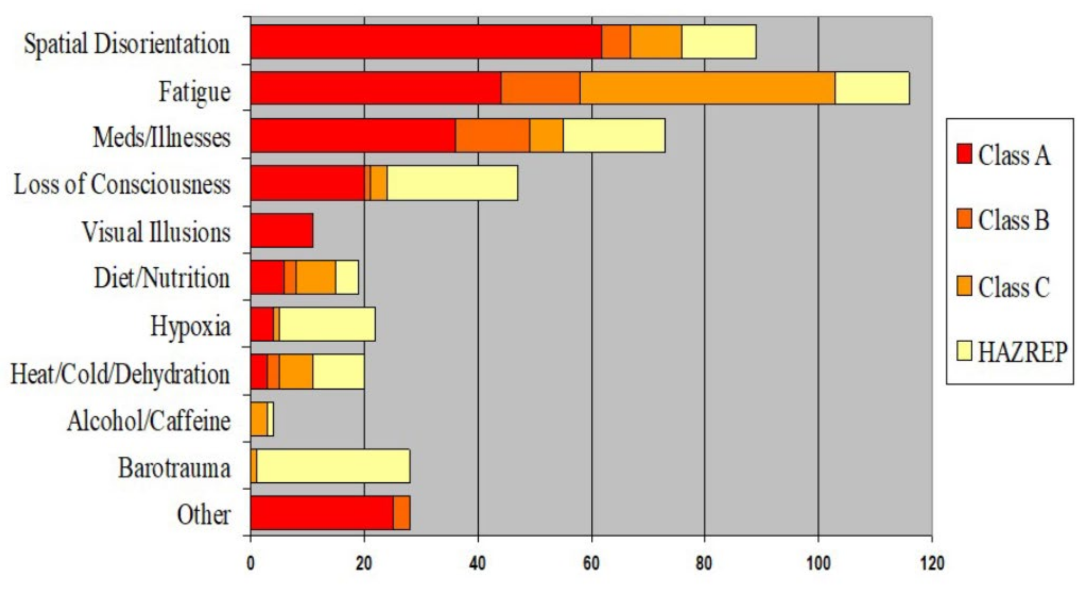

Figure 2. Bar Graph of Contributing Factors for Aviation Mishaps. Source: Shattuck (2021).

E. FATIGUE IN MILITARY AVIATION POLICY

All branches of the armed forces address aviation policies in roughly the same way. They release one universal document that applies to every member of the service and all aviation missions conducted within that service. Local units, squadrons, and air wings can then create policies that apply specifically to that unit. These local policies can only be more restrictive than the policy set forth in the universal governing documents. Therefore, by necessity, the governing document is vague to allow the local unit commanders to augment or clarify as needed. In general, the services' universal governing documents address homeostatic fatigue in the same way, by specifying crew hours similar to Table 1 created by Maynard. Conversely, each service addresses circadian fatigue in different ways.

Table 1. Breakdown of Crew Rest Hours and Mission Time for Military Aviation. Source: Maynard (2008).

United States Military							
		Flight Limitations					**Rest**
	Citation	**24 Hours**	**7 Days**	**30 Days**	**90 Days**	**365 Days**	**24 Hours**
Navy and Marine Corps	OPNAVINST 3710.7	6.5 (single pilot)/ 12 (other aircraft)	30	65	165	595	8
Air Force	AFI 11–202	12 (fighter)/ 16 (transport)	56	125	330	---	12
Army	AR 385	---	---	---	---	---	---
Coast Guard	COMDINST 3710.1	8-12 (pressurized)/ 6 (rotary)	50	125	---	---	10
Civil Authorities							
	Citation	**Flight Limitations**					**Rest**
United States	GPO Access	8	30			1000	9
United Kingdom	Civil Aviation Authority	10 to 13 +2 aircrew*	55*			1000	9
Canada	Transport Canada	8	60	150	450	1200	10
Australia	CAO 48	8	30			1000	9 to 11
note: all times are given in hours the absence of regulation is represented by dashed lines (---)							
*** Time for duty periods that are not Flight Time**							

1. Marine Corps/Navy Policy

Marine Corps and Navy aviation are governed by the "*General Flight and Operating Instructions Manual*" (also known as NATOPS). The authors of this document deemed that knowledge of circadian rhythms was important and included an entire section explaining terms relating to circadian rhythms and fatigue. No other service has a section this large in their main text. This *NATOPS* section discusses the conditions that can lead to circadian misalignment and attributes circadian misalignment to degraded performance. Navy policy addresses circadian rhythms saying: "Changing local sleep/awake periods or rapidly crossing more than three time zones disrupts circadian rhythms and can cause a marked decrease in performance" (DON, 2017, p. 188). However, no definitive policy or directives are given for mitigating these detrimental effects. The authors are primarily advising and leaving any final decision whether to fly up to the unit's chain of command or to the individual pilot.

2. U.S. Air Force Policy

The main U.S. Air Force document disseminating aviation policy is *Air Force Manual 11–202 V3*. This manual has the least guidance related to circadian rhythms of any of the services, which is not to say that the Air Force does not account for fatigue due to circadian misalignment (Department of the Air Force, 2022), rather it is done at specific units. These units have sophisticated scheduling methods that take time zone, duty history, and mission into account when scheduling flights. The USAF Air Mobility Command uses Aviation Operational Risk Management (AvORM) which has color coding to show when a pilot's performance level is predicted to be dangerously low. An example of this scheduling tool is shown in Figure 3.

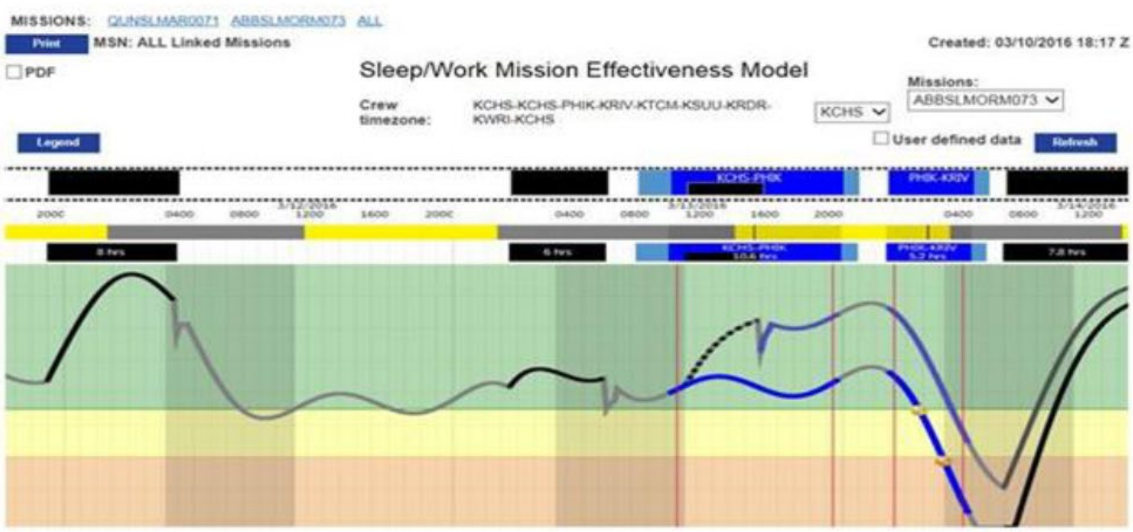

Figure 3. Example of Output from AvORM. Source: Commander Air Mobility Command (2020).

3. Army Policy

The overarching governing document in Army Aviation is the *Army Aviation Standard Operation Procedures (SOP)*. It does not specifically mention circadian rhythms, but there is policy guidance that touches specifically on jetlag. In Chapter 5, Operating Procedures, the SOP states: "Time zone changes between 6 and 12 hours require a 24-hour adjustment period before beginning missions. Changes greater than 12 hours require a 48-hour adjustment period before beginning missions" (Department of the Army, 2018, p. 100). This information is the closest any of the services' overarching policy documents comes to specific guidance in relation to circadian rhythms.

4. Coast Guard Policy

The Coast Guard disseminates most of its aviation policy through one controlled document, *The Coast Guard Air Operations Manual COMDINST 3710.1I.* This document has a crew endurance section that aligns largely with Table 1. It has no specific regulation on the scheduling of night-to-day shifts and the aircrew is largely relied on to report their fitness for flight. Appendix B of *COMDTINST 3710.1L* delves into aircrew fitness and there is a section that acknowledges "fatigue as a significant factor impacting aircrew judgment and operational performance" (COMDTINST, 2021, p. B-4). This section goes on to discuss night shift work in the operational aviation sphere dubbed, "reverse cycle operations." Several recommendations are made regarding achieving the best circadian entrainment going into extended night flight operations. Policymakers here seem to recognize the importance of light and circadian entrainment, but there are no policy mandates in this section, only recommendations to individual pilots and unit commanders (USCG, 2021).

F. APPLICATIONS OF THE RESULTS OF THIS STUDY

The scientific literature suggests that fatigue is a serious issue within the aviation and mitigating it will help prevent future mishaps. The current Armed Forces policies do address the fatigue that results from the homeostatic cycle by limiting crew hours and ensuring that there is crew rest before a scheduled mission. However, few mechanisms are in place to address the fatigue that results from misalignment with a pilot's circadian rhythm. This study aims to explore a potential material solution to this capability gap by using light as a zeitgeber to cause a phase delay in the participants' circadian rhythms, allowing them to adapt more efficiently to a night flying regime.

III. METHODS

A. EXPERIMENTAL DESIGN

This study assessed how circadian misalignment and entrainment affect aviation performance. Other studies have been conducted using light treatment to shift DLMO (Lammers-van der Holst et al., 2021; Phillips et al., 2019). The current study aimed to shift DLMO in a shorter period, potentially within 24 hours, as operational necessity dictates that pilots may only have one day to shift schedules. To this end, we conducted a within-subject quasi-experimental study using a flight simulator with aviation tasks. Below is a diagram of our experimental design.

$$O_P - \quad O_{A1\text{-}3} \quad - O_{M1\text{-}13,\, A1\text{-}3} \quad - X_{\text{Light Treatment}}\ O_{M1\text{-}13,\, A1\text{-}3} \quad - O_{M1\text{-}13,\, A1\text{-}3}$$

Each of the main scripts represents either an observation (O) or a treatment (X). The first observation O_P was the recruitment data we gathered from the participants prior to their time in the flight simulator. The subscripts A1-3 represent the observations that we took from the simulator events, and the subscripts M1-13 represent the melatonin assays collected every 30 minutes for the 6 hours the participants remained in the lab each of three consecutive nights.

B. PARTICIPANTS

The study was conducted at the Naval Postgraduate School and was open to both students and faculty on campus. Researchers solicited participants through an email sent to all students and staff and with an electronic poster on the student portal. Participants were required to have been trained in military aviation and to have had at least one tour with military aviation as their primary duty. Participants also could not be taking any medication that would affect their melatonin levels. Researchers did allow participants to take nicotine or caffeine substances, but they needed to abstain from them for four hours prior to taking any melatonin samples.

C. PROCEDURES

1. Sequence of Events

Seven to ten days of data were collected for each participant prior to the study, followed by four in-lab data collection sessions to assess melatonin levels and performance on three simulated flights. The first session was a baseline session to establish flight performance during the day, presumably without fatigue. The second session was at night and measured DLMO and flight performance in a fatigued state. The third session introduced the light treatment while the fourth and final session measured DLMO and fatigue post-treatment.

Participants in the three-night study completed one daytime flight and three nighttime flights in a flight simulator as shown in Figure 4. Each flight consisted of three separate profiles, simulating coming down from altitude to land at an airport. On Day 1, participants performed a daytime flight (morning) and, on Night 1, a nighttime flight (1.5 hours after habitual bedtime). Prior to the first nighttime flight, the participants were kept in a dimly lit room (less than 10 lux of background illumination) for four hours. On Night 2, the participants performed another nighttime flight (also 1.5 hours after habitual bedtime). Prior to this second nighttime flight, participants underwent a treatment of 1,000 lux blue-enriched near-white light for four hours. On Night 3, participants performed a final nighttime flight (post-light flight; 1.5 hours after habitual bedtime). Prior to the final flight, participants were kept in the same dimly lit room for four hours. Researchers collected saliva samples for melatonin testing, with samples collected every half hour during the three nights that the subjects were in the lab. Participants also completed the Bedford Workload Scale assessment (Roscoe & Ellis, 1990) for each of their simulator evolutions, and periodically rated their sleepiness on the Karolinska Sleepiness Scale (Akerstedt et al., 1990).

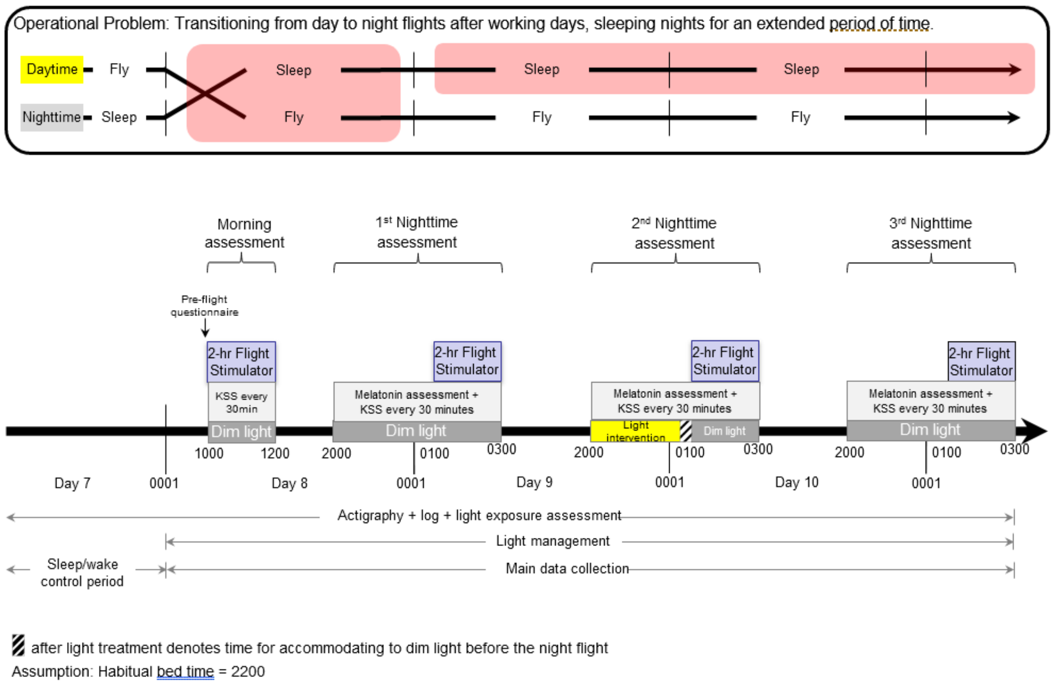

Figure 4. Example Study Schedule with 2200 as Participant's Habitual Bedtime. Source: Shattuck et al. (2021).

2. Simulator Procedure

The simulator flights were split into three separate events. The participants used instruments within the cockpit to fly from altitude down to three airports, San Francisco International, Las Vegas International, and Martha's Vineyard Regional. This method of not using visual cues from outside the aircraft, but solely relying on the gauges within the aircraft is called instrument flying. Larger airports have charted paths and radio beacons that allow pilots to navigate from a cruising altitude down to just above an airport without running into any hazards like mountains, buildings, or large antennas. These charted paths are called approaches.

The specific type of approach used for the three events of each flight was the instrument landing system (ILS) approach. The ILS approach consists of two sets of beacons that emanate from the airport. One set is arranged to tell the vertical distance of an aircraft from the centerline or glideslope. The other beacons tell the horizontal deviation or course deviation from the centerline. Radiating out from the airport, these beacons create an invisible cone in the airspace. The pilot's goal is to stay in the center of that cone using a Course Deviation/Glideslope Indicator (CDI). It is important to note that the distance that the CDI reads is angular. As the pilot closes the distance to the airport, the readings are significantly more sensitive. The pilot uses this CDI to read horizontal and vertical deviation and the airspeed indicator. These are the three performance metrics the study used to measure pilot performance over the study period.

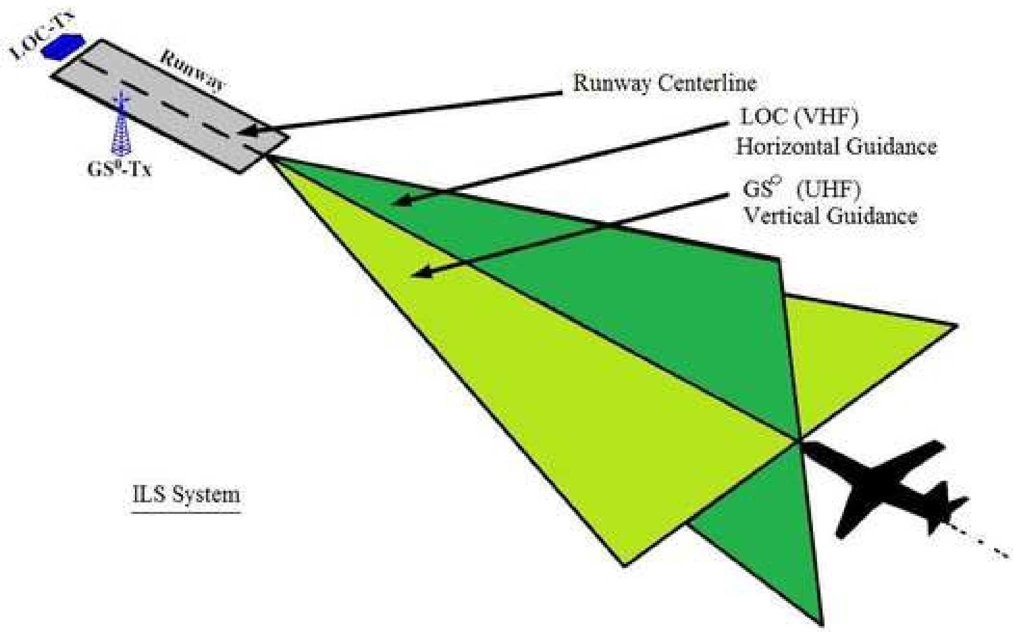

Figure 5. Diagram of ILS Approach Denoting Vertical and Horizontal Radio Beams Used for Guidance. Source: McAliece (2019).

3. Metrics Used

Indicated Airspeed (IAS) is the airspeed detected by the aircraft sensors as the aircraft moves through the air. For each of the flights, participants were instructed to maintain airspeed as close to 60 knots as possible. Note: When flying an approach, airspeed is determined primarily by the position of the nose or pitch. Bringing the nose down or pitching forward will increase airspeed and pitching back will decrease airspeed. Pitching will also result in a change in altitude if there is no change in aircraft power. Aircraft power is changed by adjusting the throttle. Reducing power will increase the rate of descent while increasing the power will decrease the rate of descent.

The participants followed the glideslope down to the airport in each of the profiles. The CDI gives them an indication of their vertical deflection above or below the glideslope and they adjust accordingly. If they are above glideslope, they reduce power to increase their rate of descent to get back on glideslope. If they are below glideslope, they increase power, decreasing their rate of descent and rising back up on glideslope. The participants were instructed to have as little vertical deflection as possible during each of the flight profiles.

The participants also used the CDI to determine their horizontal deflection to the right or left of the final approach course. To correct any deflection, the participants would turn the aircraft by rolling the wings in the direction they want to turn and pitching up. This pitching up leads to a reduction in airspeed that needs to be corrected by pitching back down at the end of the maneuver. This change in pitch would affect the rate of descent which would necessitate a change in power. Thus, all changes in the controls are intertwined with one another and require a high degree of concentration to maintain the given parameters.

4. Measurements Taken

The data used for flight performance analysis were taken at the point at which the participants passed the final approach fix until they were 300 feet above the runway. The Federal Aviation Administration's definition of a final approach is the flight path from the final approach fix, a specific distance from the airport designated on a map, to the runway. It is critical to follow the given parameters in this portion of the approach. In actual flight, any major drop in performance could mean crashing the aircraft. The pilots must be especially focused during this time. This period is also when the participants' CDI was most dynamic, and their workload was the highest. Measurements from 300 feet above the runway to landing were excluded because participants had the runway in sight and were using outside visual cues to land. In effect, they would no longer be flying using the instruments.

The participants also needed to respond to outside factors like wind and turbulence when conducting the ILS approach at both Las Vegas and Martha's Vineyard as shown in Table 2.

Table 2. Environmental Settings for Flight Profiles A, B, and C

Parameter	Profile A	Profile B	Profile C
Filename	ProfileA_SFO_Day ProfileA_SFO_Night	ProfileB_LAS_Day ProfileB_LAS_Night	ProfileC_MVY_Day ProfileC_MVY_Night
Airport	KSFO	KLAS	KMVY
ILS Approach	28R	01L	24R
Navaid	111.7	110.7	108.7
Winds	None	360/4 @ 6291'MSL 270/6 @ 3279'MSL	360/9 @ 3911'MSL
Cloud Layers	None	Broken Cumulus 6586' -4586'MSL	Broken Cumulus 22K'-949' MSL
Turbulence	None	Mild	None
Storminess	None	None	Mild
Precip	None	None	Light
Runway	Dry	Dry	Damp
Time (day/night local)	1000L or 0100L	1000L or 0100L	1000L or 0100L

D. EQUIPMENT

1. Ōura Ring

The Ōura ring was the primary means of identifying habitual bedtime from the seven to ten days prior to the start of the performance assessment part of the study. Ōura rings are multi-sensored devices worn by the participant that connect wirelessly to a personal cell phone. They have been excellent at providing data in other studies (de Zambotti et al., 2017; Chee et al., 2021), but the participants were required to charge them periodically which introduced some risk to our data collection.

2. Actigraphy Watch

The Respironics Actiwatch Spectrum Plus actigraphy watch was used as a backup sensor to verify habitual bedtime. Participants wore it on their wrists; the accelerometer in it tracks motion (Martin & Hakim, 2011; Miller et al., 2010). A separate device was used for the PVT portion of data collection for the last three participants. The Motionlogger

(AMI, Inc.) has a setting that allowed participants to conduct a 3-minute PVT prior to each simulator profile (Matsangas et al., 2019).

3. Assessment of Salivary Melatonin

Participants deposited saliva into Salivettes (Sarstedt, Germany), every thirty minutes during the three nighttime sessions. These samples were stored in a freezer capable of keeping a temperature of -20° C before sending them to a testing center, SolidPhase Laboratory, Portland, Maine (Kazemi et al., 2018; Kennaway, 2019). These assays allowed the calculation of melatonin onset (a proxy for each subject's circadian rhythm) across the three nights of the study (Keijzer et al., 2011).

4. Simulator

Researchers employed two different computers to run the aviation simulation software. The first was used for participants one through seven. It was an Alienware laptop with an Intel Core i7-9750H CPU 2.6 GHz processor with 16 GB of installed ram. The second computer was used for participants eight, nine, and ten. It was a Dell desktop with an Intel Xerox W-2225 CPU 4.6 GHz processor with 32 GB of installed ram. In both cases, a cockpit view of the aircraft was displayed on a fifty-five-inch Samsung TU8000 with a Logitech G Pro flight yoke system. The researcher monitored the flight from behind the participant using a laptop or desktop monitor. These computers ran X-Plane 11.53 (Laminar Research) simulation software which fed simulator data (Appendix C) to a notepad document that was later converted to an Excel spreadsheet (Taranto, 2020).

5. Treatment Room

Participants sat in a windowless room inside another windowless room for the 4.5 hours leading up to the simulator flight. On Night 1 and Night 3, this room was kept at a light level of less than ten lux; the outer room was also kept dim to prevent ambient light from leaking in. On Night 2, the light treatment, this room had an ambient light of 1,000 lux.

6. Treatment Devices

Light boxes manufactured by Circadian Positioning Systems, Inc. (CPS) were used to control the level of ambient light in the treatment room. During Night 2, the light boxes were programmed to create an ambient lux level of ~1,000 lux of high-energy, blue-enriched white light. The participant was free to move about the room and did not need to look directly at the lights. However, they needed to generally face toward the lights for the duration of the treatment time. During Night 1 and Night 3, the ambient light was no greater than 10 lux. During that time, the participant was not in an area with more than 10 lux unless their eyes were covered with welder's goggles.

7. Questionnaires and Surveys

Seven to ten days prior to their time in the lab, participants completed a questionnaire during the consent phase of the study. This first questionnaire assessed their experience in aviation, any potential biological factors that could affect circadian rhythm or melatonin production, and their tendency toward morningness or eveningness (Adan & Almirall, 1991). When they arrived for their day flight, participants completed a second questionnaire consisting of the Epworth Sleepiness Scale, the Karolinska Sleepiness Scale, and the Pittsburgh Sleep Quality Index scale (Akerstedt et al., 1990; Nishiyama et al., 2014). For each night session, the participants completed an initial questionnaire to ensure they were able to participate that evening, a Karolinska Sleepiness Scale every thirty minutes, and a Bedford Workload Scale Index for each of the three flight evolutions. These instruments can be found in Appendix A.

E. ANALYSIS ROADMAP

Melatonin levels for each participant over the three nights were assessed by SolidPhase Laboratory. Using pairwise analysis and Wilcoxon signed rank tests, these data were then assessed. Detailed information regarding melatonin analysis and results can be found elsewhere (McDonough, 2021; Shattuck et al., 2021).

Flight performance was evaluated in the simulator during the day, before the treatment, and the following day after the light intervention. The analysis looked for any change between these three conditions. For the last three participants, performance in the simulator was also compared against a PVT completed by pilots before each simulator evolution (Basner & Dinges, 2011). Pairwise analysis of PVT data was conducted with the Wilcoxon signed rank test.

Performance data were collected for the duration of each of the three flights in 1-second increments. The main focus of the analysis was to assess differences in flight performance between Night 3 (after the light treatment in Night 2) and Night 1 (before the light treatment). The secondary focus was to compare Night with Day performance. Theoretically, these would be the times at which the participant is the most awake. There should be a marked difference between those flights and the Night 1 flight in which the participant should have been experiencing the highest levels of fatigue. The data were arranged to show any centerline, glideslope, or target airspeed deviation as a difference from zero and as a drop in performance. Using the Wilcoxon signed rank test, we conducted pairwise analyses to assess differences in flight performance metrics (airspeed difference from 60 knots, horizontal deflection, and vertical deflection, error of these metrics) and PVT reaction time. Analysis was conducted using JMP software (JMP Pro 16; SAS Institute; Cary, NC).

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IV. RESULTS

Analysis of melatonin levels between Night 3 and Night 1 showed a significant shift in DLMO for all participants (mean = 1 hour and 19 minutes plus or minus 22 minutes (Wilcoxon signed rank test, $S = 22.5$, $p = 0.004$). Individual DLMO shifts ranged from 53 minutes to 1 hour 56 minutes. Detailed information regarding melatonin and DLMO can be found elsewhere (McDonough, 2021; Shattuck et al., 2021).

A. FLIGHT PERFORMANCE METRICS

Results presented herein are based on data from the final approach portion of the flight profiles aggregated by profile. Detailed information regarding raw data is shown in Appendix C.

1. Aircraft Deflection

In all figures showing horizontal deflection, positive values denote an average deflection left of course, whereas negative values denote an average deflection right of course.

a. Horizontal Deflection

The box plot below shows horizontal deflection averaged by flight profile. Results show that in most flight sessions, participants had an average horizontal deflection to the right. Since each flight profile had distinct characteristics, though, the following sections are focused on each flight profile separately.

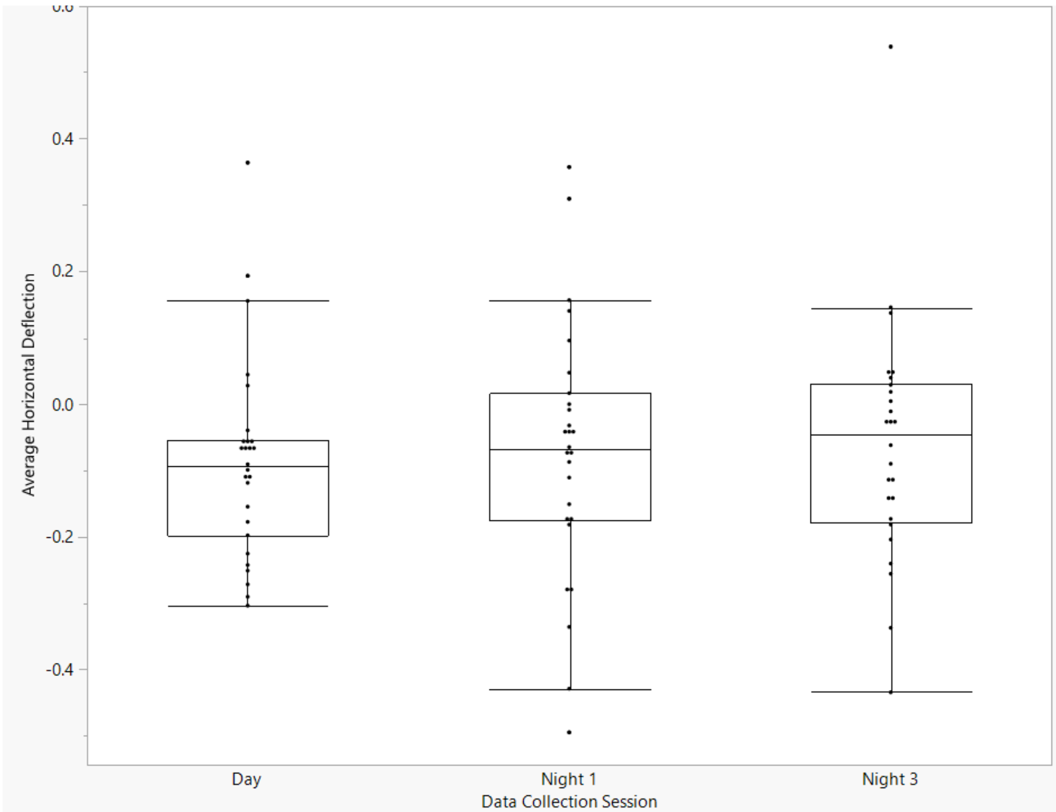

Figure 6. Average Horizontal Deflection of All Participants and Flight Profiles

(1) Profile A

We used pairwise analysis based on the Wilcoxon Signed Rank test to assess differences between conditions (Day, Night 1, Night 3). Results showed that the average horizontal deflection differed between Day (M = -0.080, SD = 0.022) and Night 1 (M = -0.038, SD = 0.035; Wilcoxon Signed Rank test, S = 17.0, p = 0.015). Average horizontal deflection differed between Day and Night 3 (M = -0.020, SD = 0.056; Wilcoxon Signed Rank test, S = 15.0, p = 0.039). We did not identify statistically significant differences in horizontal deflection between Night 3 and Night 1 (Wilcoxon Signed Rank test, S = 6.0, p = 0.460). Figure 7 shows average horizontal deflection in flight profile A by data collection session (Day, Night 1, Night 3).

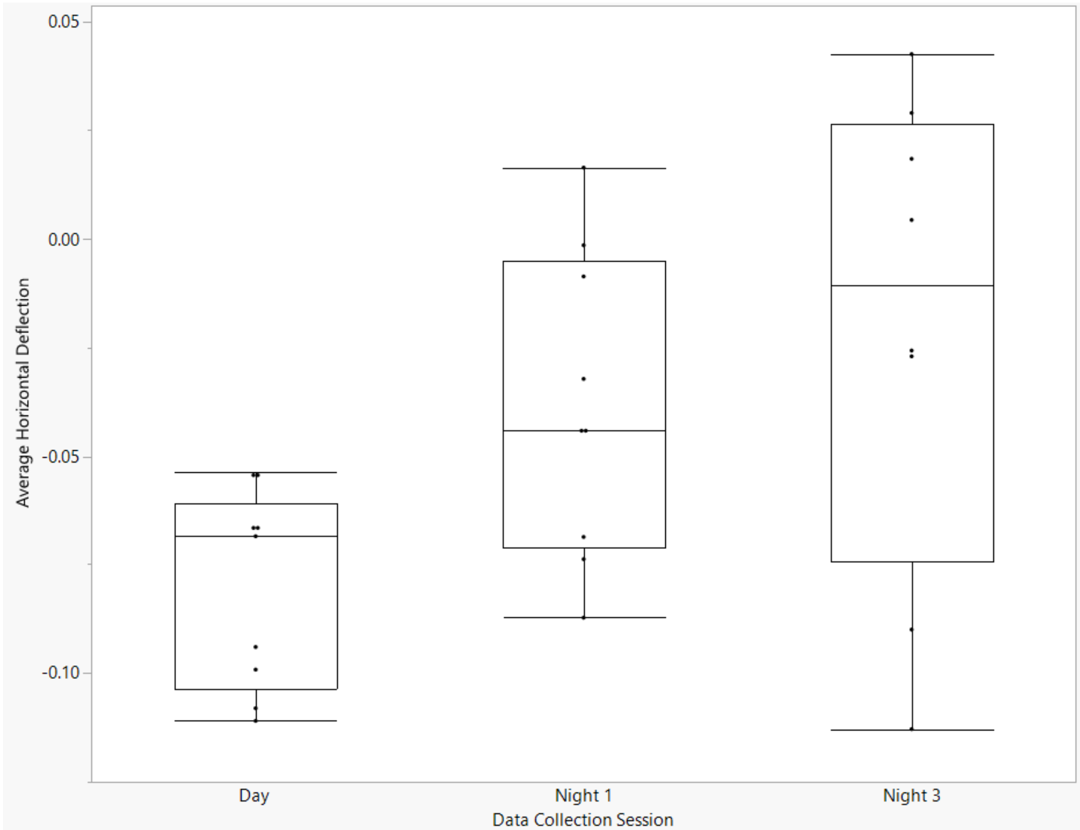

Figure 7. Average Horizontal Deflection in Flight Profile A by Data Collection Session (Day, Night 1, Night 3)

(2) Profile B

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = -0.227, SD = 0.103), Night 1 (M = -0.277, SD = 0.122), and Day (M = -0.235, SD = 0.050) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.570$). Figure 8 shows average horizontal deflection in flight profile B by data collection session (Day, Night 1, Night 3).

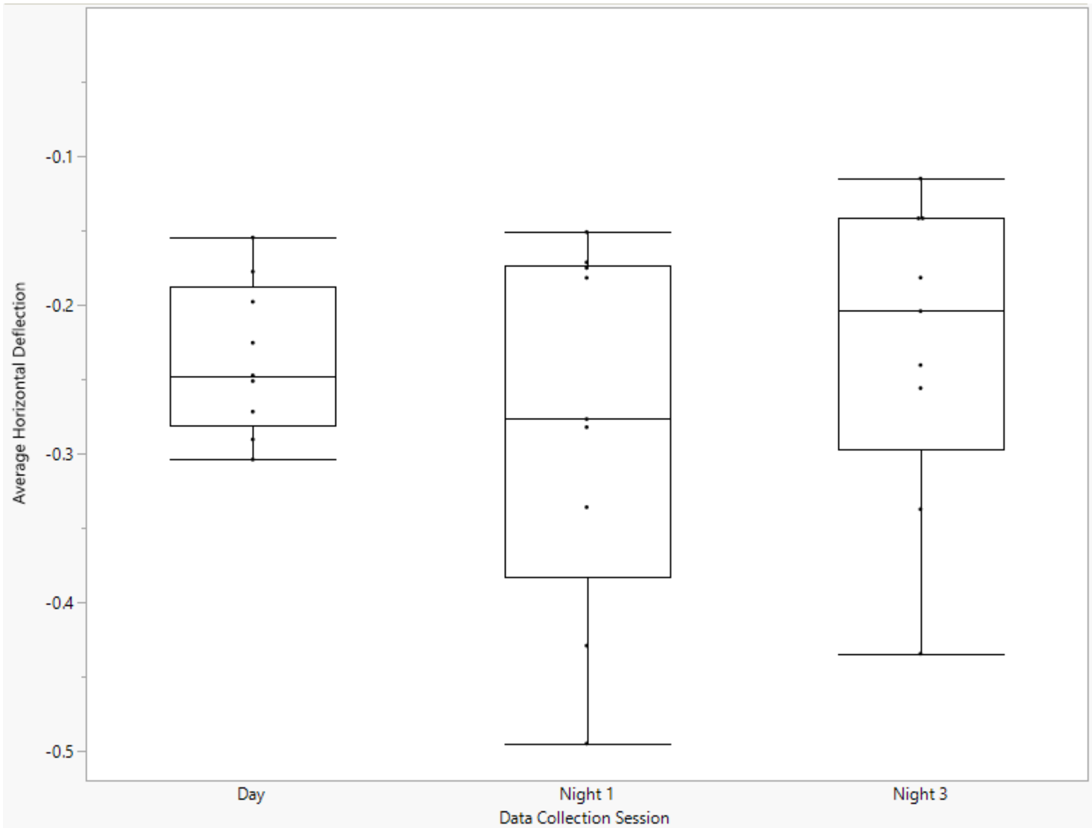

Figure 8. Average Horizontal Deflection in Flight Profile B by Data Collection Session (Day, Night 1, Night 3)

(3) Profile C

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 ($M = 0.069$, $SD = 0.201$), Night 1 ($M = 0.098$, $SD = 0.162$), and Day ($M = 0.055$, $SD = 0.154$) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.425$). Figure 9 shows average horizontal deflection in flight profile C by data collection session (Day, Night 1, Night 3).

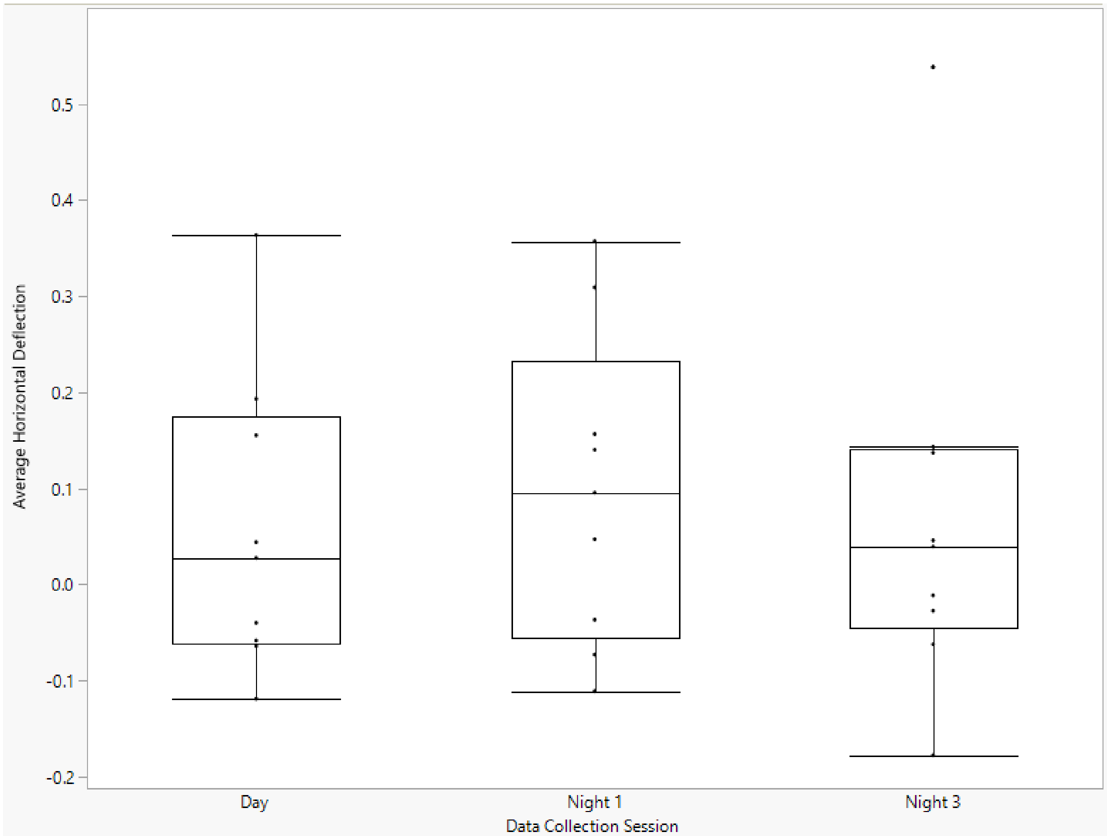

Figure 9. Average Horizontal Deflection in Flight Profile C by Data Collection Session (Day, Night 1, Night 3)

b. Vertical Deflection

Vertical deflection data of all participants can be found in Appendix C. On vertical deflection plots, the positive portion of the plot denotes when the participant was above glideslope and the negative portion of the plot denotes when the participant was below glideslope. Means for all flights and all profiles are shown in the box plot below.

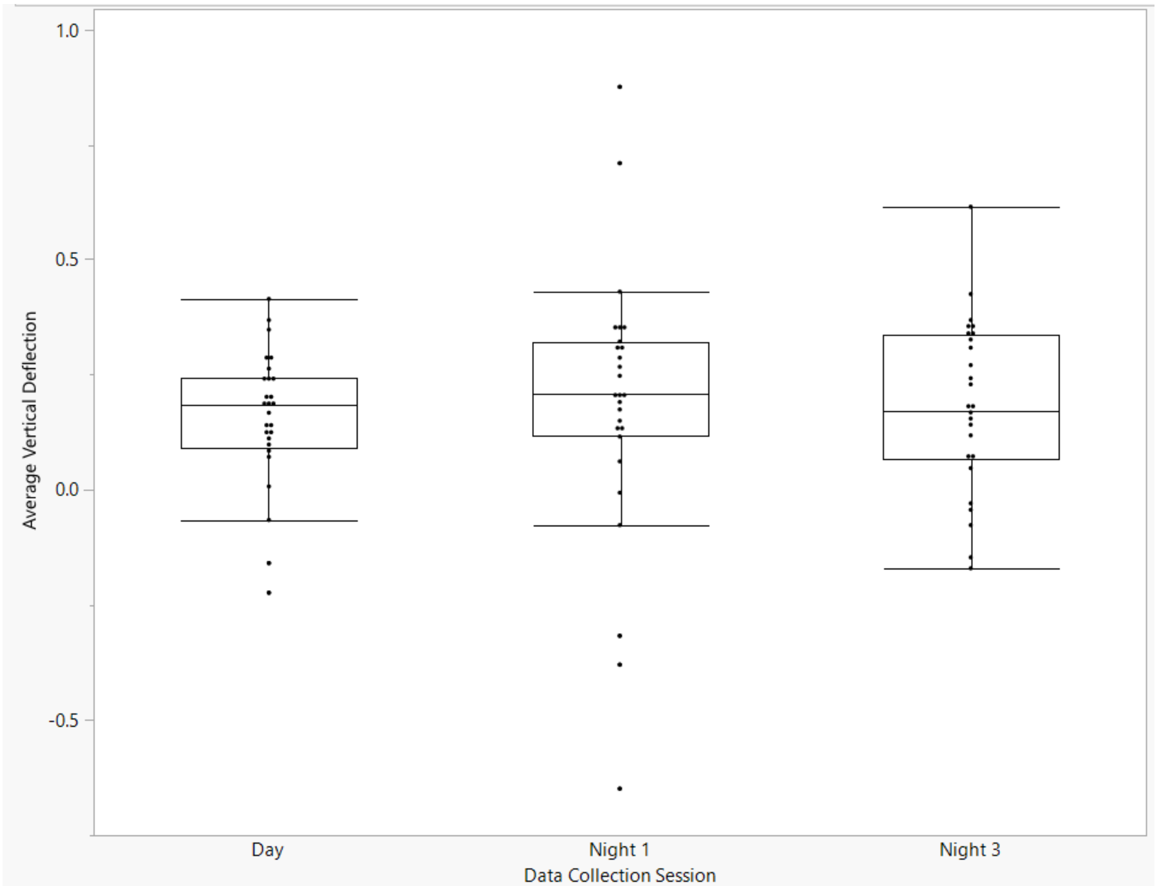

Figure 10. Average Vertical Deflection of All Participants and Flight Profiles of All Participants and Flight Profiles

(1) Profile A

We used pairwise analysis based on the Wilcoxon Signed Rank test to assess differences between conditions (Day, Night 1, and Night 3). Results showed that the mean vertical deflection differed between Day (M = 0.095, SD = 0.136) and Night 1 (M = 0.190, SD = 0.054); Wilcoxon Signed Rank test, S = 16.0, p = 0.023). We did not identify any statistically significant difference between Night 3 (M = .095, SD = 0.135) and Day (M = 0.095, SD = 0.136); and Night 3 (M = 0.095, SD = 0.135) and Night 1 (M = 0.190, SD = 0.054); (Wilcoxon Signed Rank test all p > 0.148). Figure 11 shows average vertical deflection in flight profile A by data collection session (Day, Night 1, Night 3).

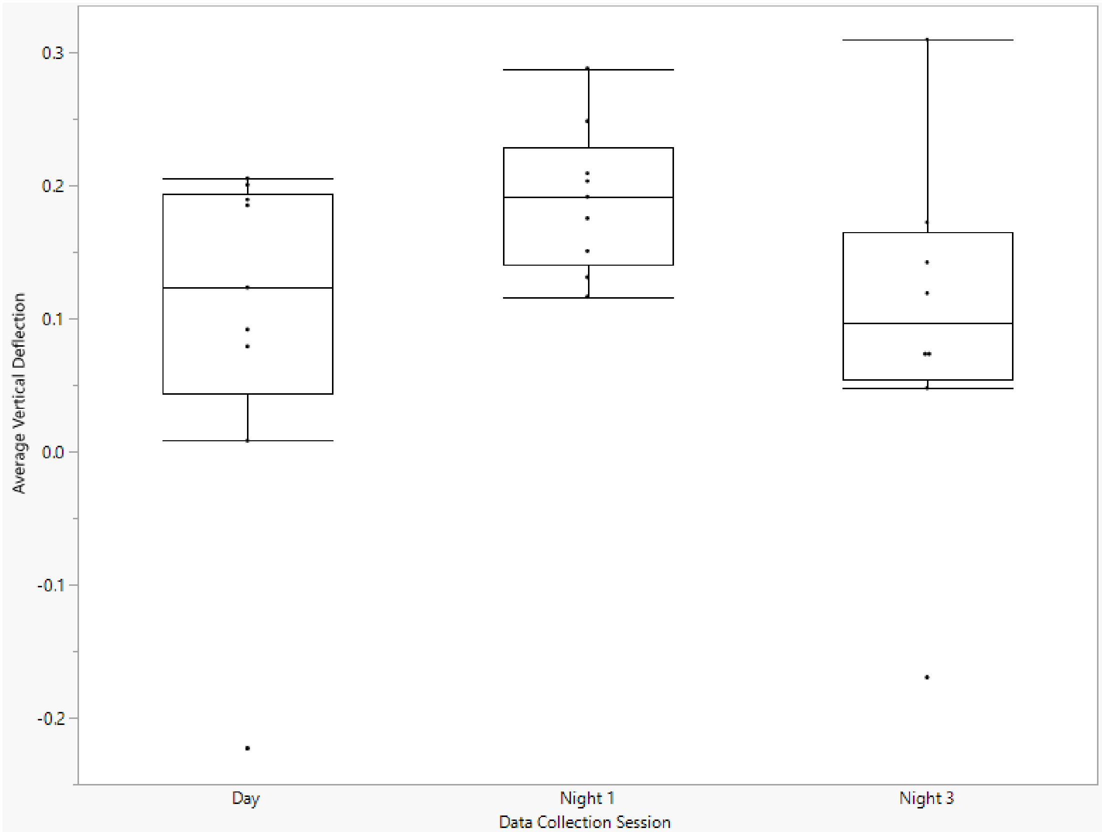

Figure 11. Average Vertical Deflection in Flight Profile A by Data Collection Session (Day, Night 1, Night 3)

(2) Profile B

Results showed that the mean vertical deflection differed between Night 3 (M = 0.352, SD = 0.123) and Day (M = 0.184, SD = 0.155); Wilcoxon Signed Rank test, S = 16.5, p = 0.054). We did not identify any statistically significant differences between Day (M = 0.184, SD = 0.155) and Night 1 (M = 0.262, SD = 0.225), and Night 3 (M = 0.352, SD = 0.123) and Night 1 (M = 0.262, SD = 0.225); Wilcoxon signed rank test, all p > 0.300). Figure 12 shows average horizontal deflection in flight profile B by data collection session (Day, Night 1, Night 3).

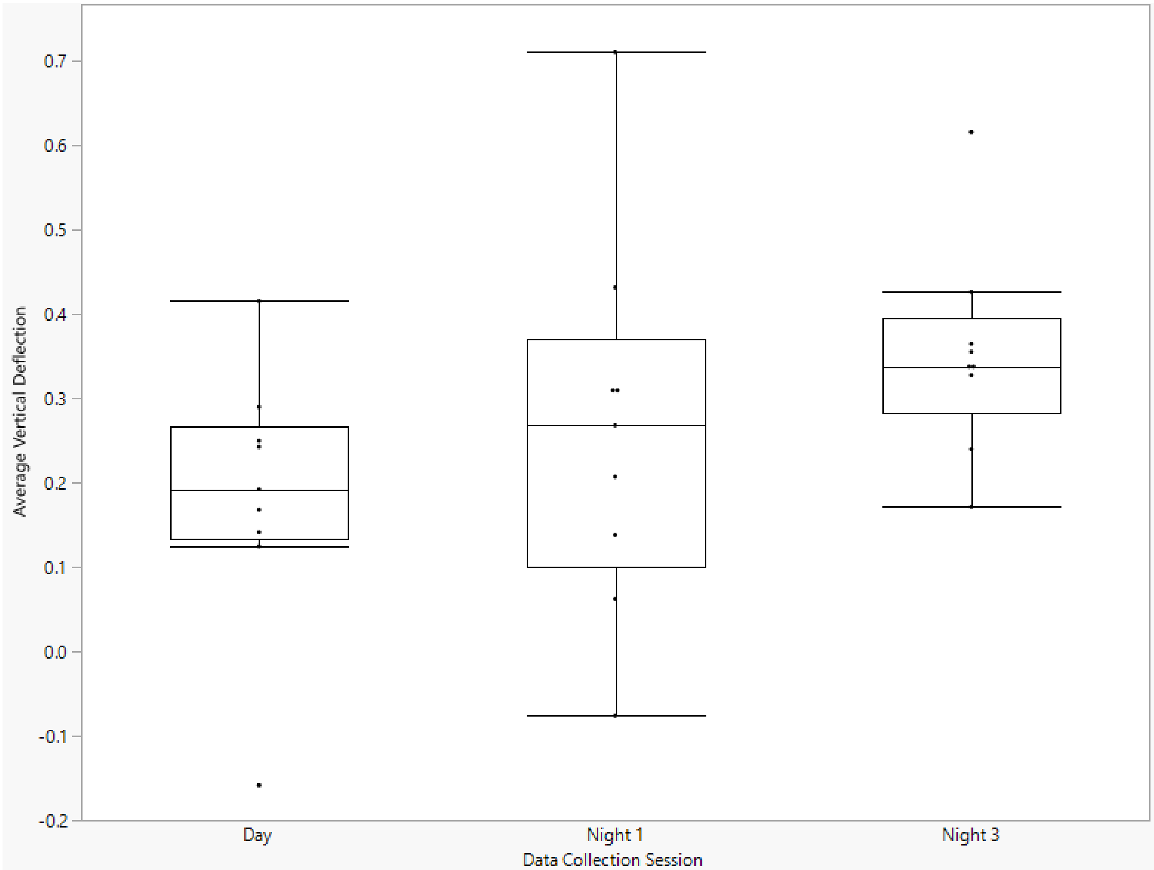

Figure 12. Average Vertical Deflection in Flight Profile B by Data Collection Session (Day, Night 1, Night 3)

(3) Profile C

Results showed that vertical deflection differed between Night 3 (M = 0.097, SD = 0.175) and Day (M = 0.195, SD = 0.142); Wilcoxon Signed Rank test, S = -15.5, p = 0.074). We did not identify any statistically significant differences between Day (M = 0.195, SD = 0.142) and Night 1 (M = .100, SD = 0.476), Night 3 (M = 0.097, SD = 0.175) and Night 1 (M = 0.100, SD = 0.476); Wilcoxon signed rank test all p > 0.496). Figure 13 shows average horizontal deflection in flight profile C by data collection session (Day, Night 1, Night 3).

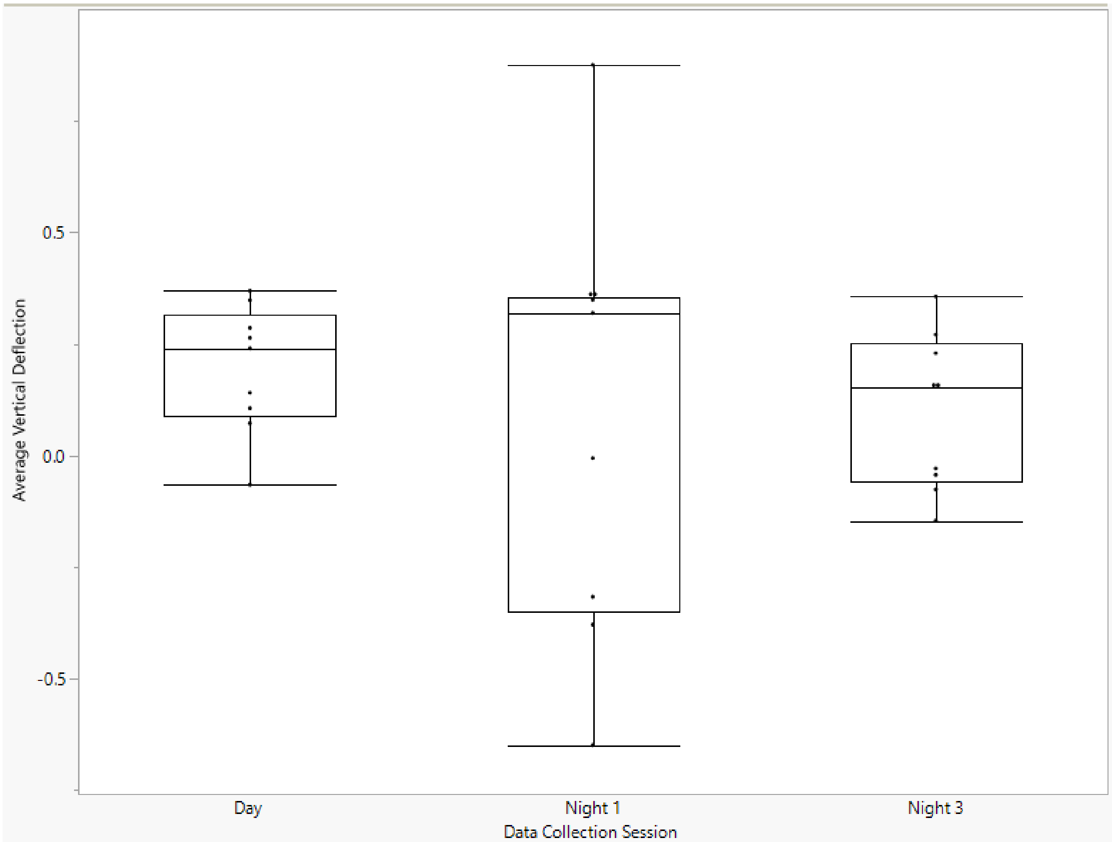

Figure 13. Average Vertical Deflection in Flight Profile C by Data Collection Session (Day, Night 1, Night 3)

c. Airspeed Difference

Airspeed difference data of all participants can be found in Appendix C. The airspeed difference is a measure of the participant's airspeed deviation from 60 knots. A negative number on the plot denotes the difference in airspeed below 60 knots and a positive number denotes an airspeed of more than 60 knots.

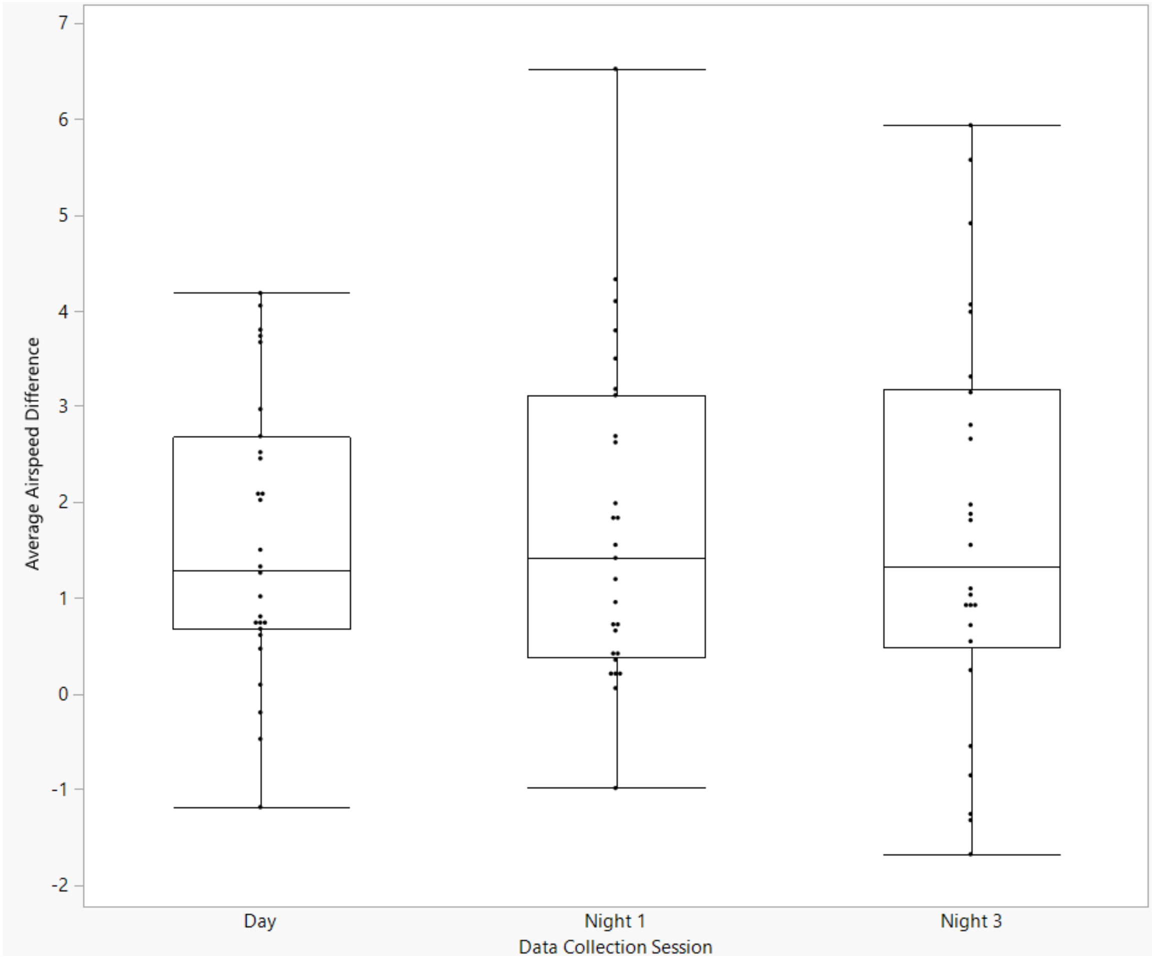

Figure 14. Average Airspeed Difference of All Participants and Flight Profiles

(1) Profile A

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 1.171, SD = 2.153), Night 1 (M = 0.743, SD = 1.073), and Day (M = 1.267, SD = 1.048) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.250$). Figure 15 shows average airspeed difference in flight profile A by data collection session (Day, Night 1, Night 3).

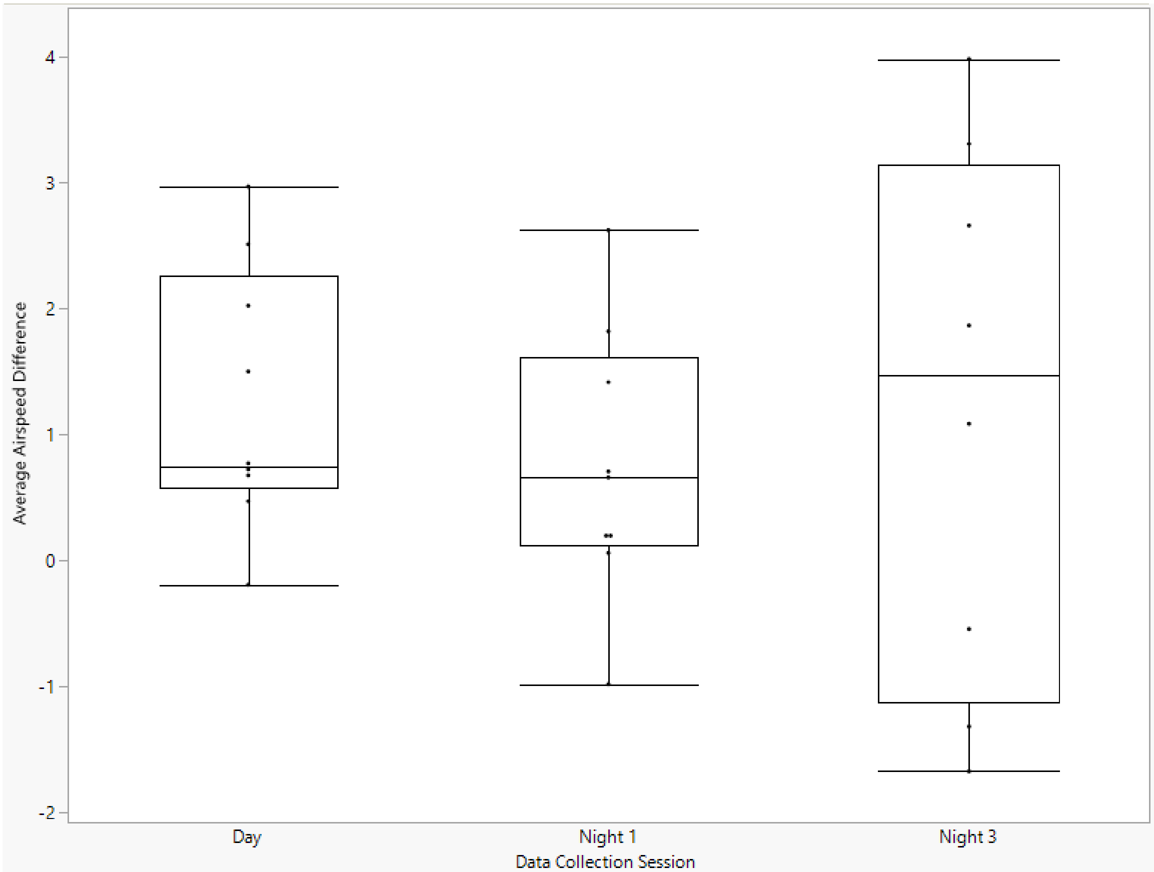

Figure 15. Average Airspeed Difference in Flight Profile A by Data Collection Session (Day, Night 1, Night 3)

(2) Profile B

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 1.372, SD = 1.496), Night 1 (M = 2.074, SD = 1.354), and Day (M = 1.840, SD = 1.761) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.250$). Figure 16 shows average airspeed difference in flight profile B by data collection session (Day, Night 1, Night 3).

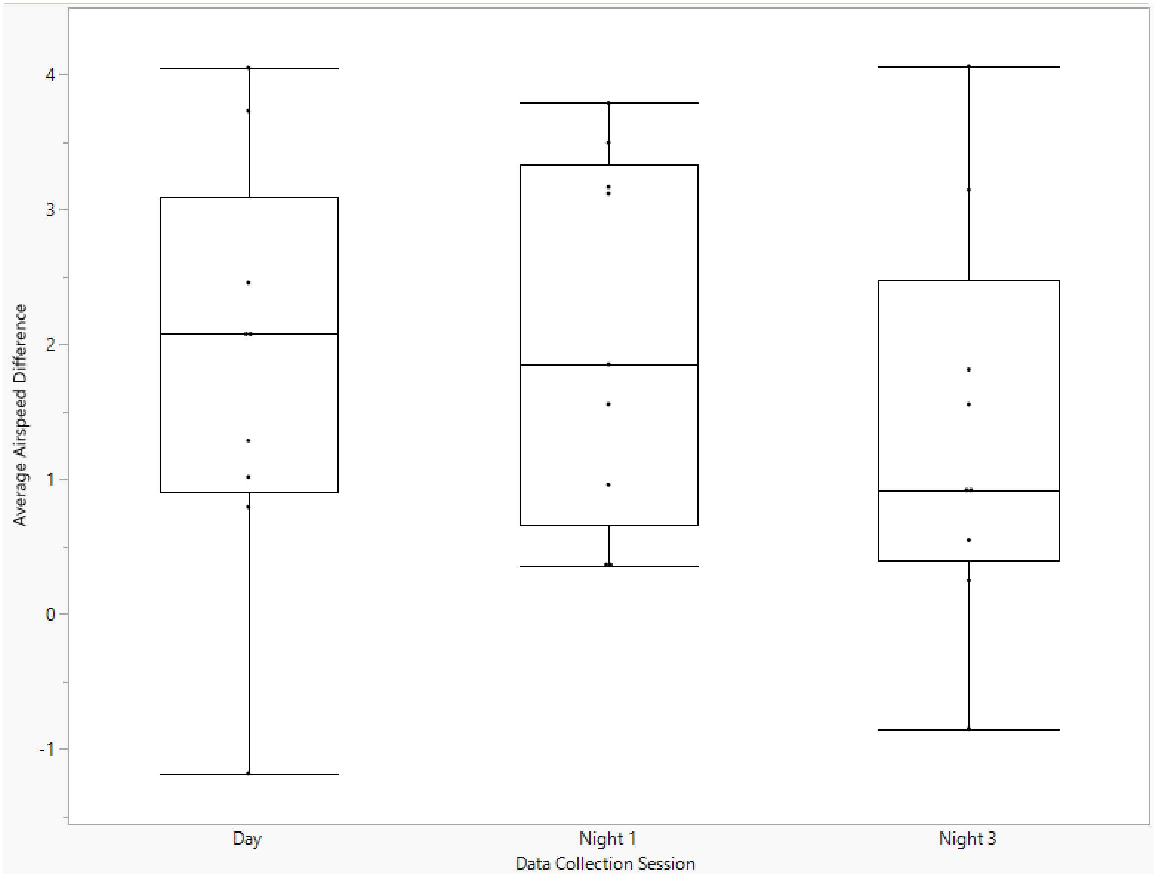

Figure 16. Average Airspeed Difference in Flight Profile B by Data Collection Session (Day, Night 1, Night 3)

(3) Profile C

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 2.511, SD = 2.488), Night 1 (M = 2.456, SD = 2.146), and Day (M = 1.811, SD = 1.587) data collection sessions (Wilcoxon Signed Rank test, all p > 0.203). Figure 17 shows average airspeed difference in flight profile C by data collection session (Day, Night 1, Night 3).

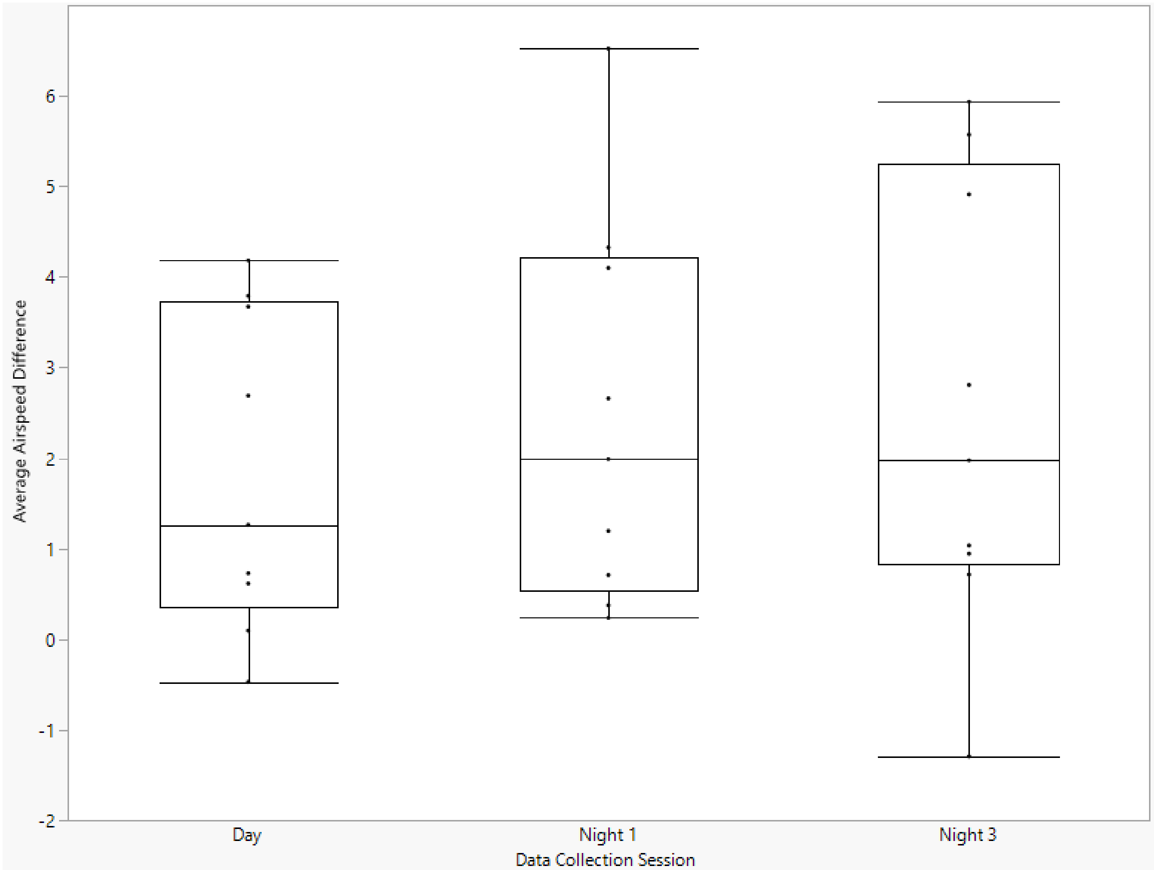

Figure 17. Average Airspeed Difference in Flight Profile C by Data Collection Session (Day, Night 1, Night 3)

d. Horizontal Error

The mean of the horizontal error for each of the approaches flown was calculated by squaring the data in the time series plots in Appendix C. All means are shown in the bar chart below. This overview of the data shows large variability among participants. The highest point in each condition is the same participant. Since each profile had different characteristics, they will be analyzed separately.

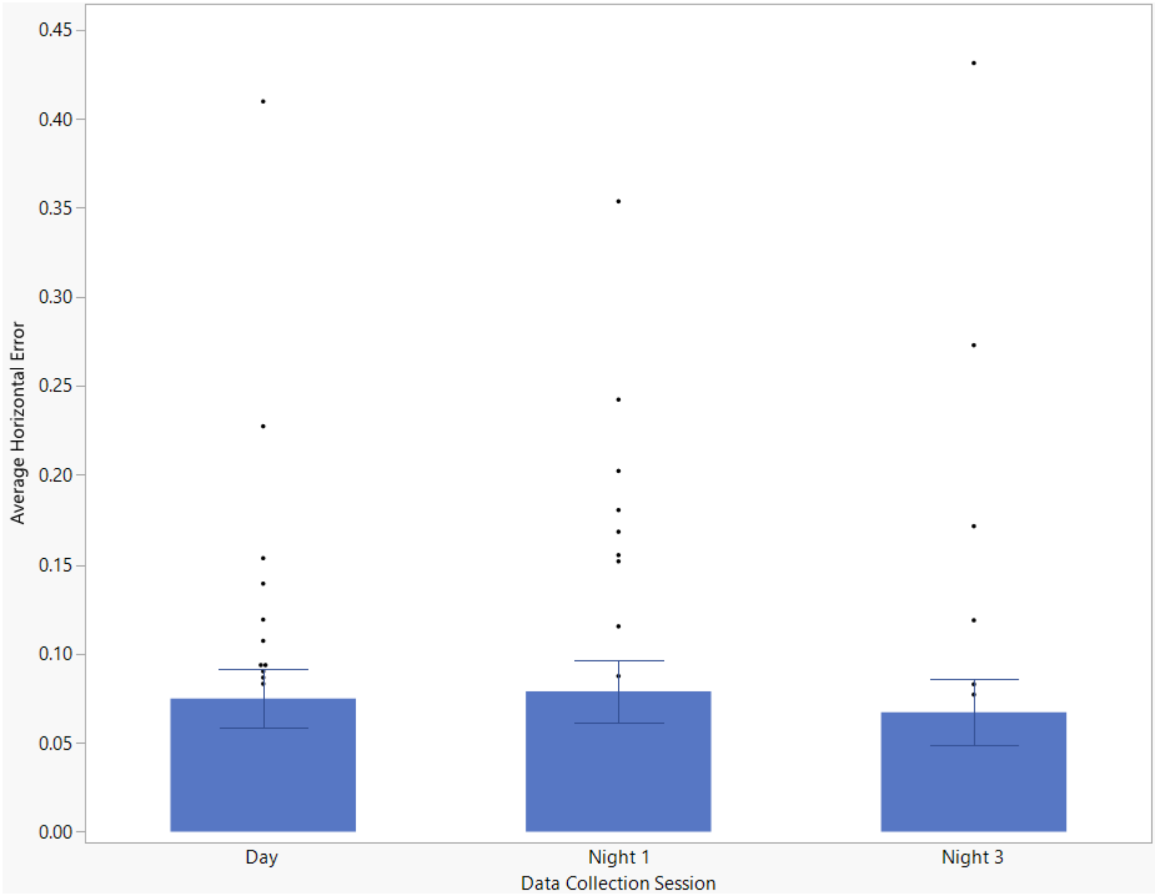

Figure 18. Average Horizontal Error of All Participants and Flight Profiles. Vertical Lines Denote the Standard Error

(1) Profile A

Results showed that horizontal error differed between Day (M = 0.013, SD = 0.004) and Night 1 (M = -0.006, SD = 0.003); Wilcoxon Signed Rank test, S = -15.0, p = 0.039). We did not identify any statistically significant differences between Night 3 (M = 0.008, SD = 0.006) and Day (M = 0.013, SD = 0.004), Night 3 (M = 0.008, SD = 0.006) and Night 1 (M = 0.006, SD = 0.003); Wilcoxon signed rank test all p > 0.109). Figure 19 shows average horizontal error in flight profile A by data collection session (Day, Night 1, Night 3).

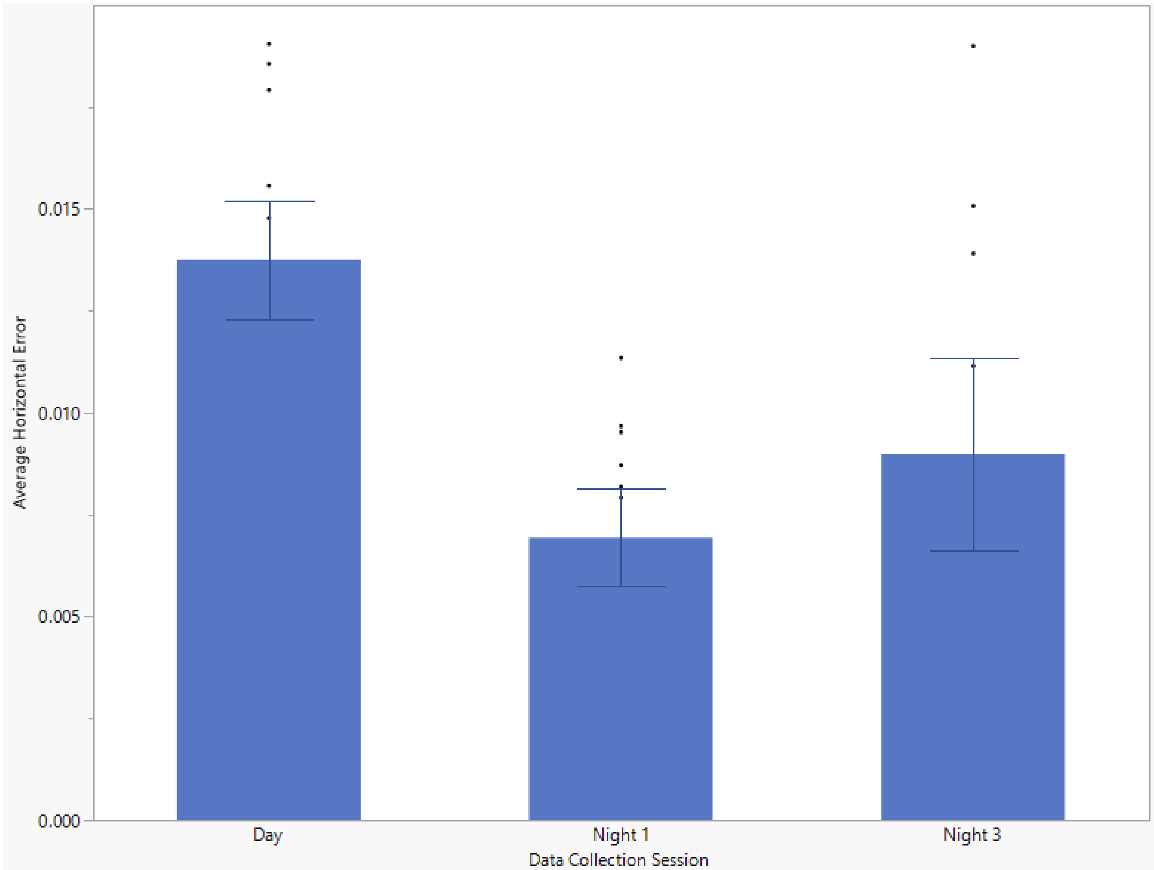

Figure 19. Average Horizontal Error in Flight Profile A by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(2) Profile B

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 ($M = 0.094$, $SD = 0.081$), Night 1 ($M = 0.126$, $SD = 0.105$), and Day ($M = 0.088$, $SD = 0.033$) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.425$). Figure 20 shows average horizontal error in flight profile B by data collection session (Day, Night 1, Night 3).

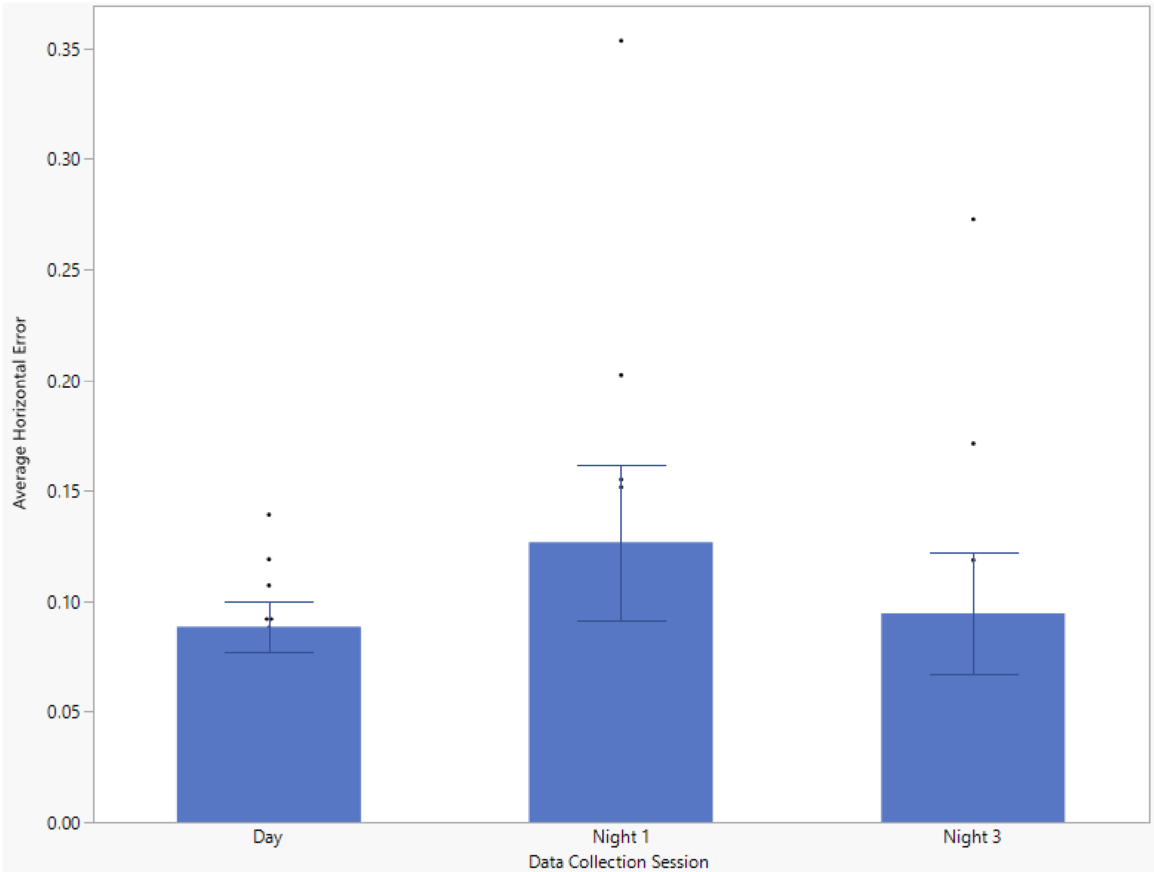

Figure 20. Average Horizontal Error in Flight Profile B by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(3) Profile C

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 0.091, SD = 0.128), Night 1 (M = .102, SD = 0.076), and Day (M = 0.121, SD = 0.126) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.570$). Figure 21 shows average horizontal error in flight profile C by data collection session (Day, Night 1, Night 3).

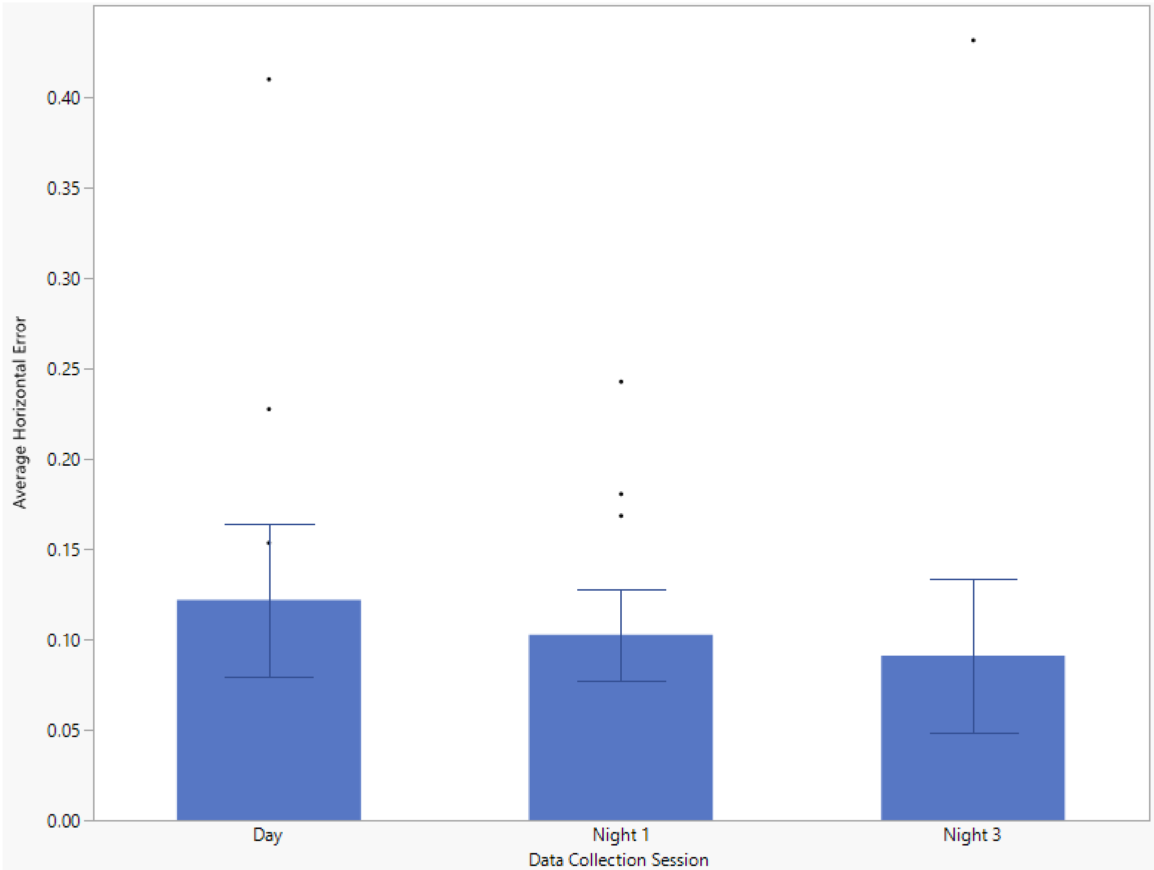

Figure 21. Average Horizontal Error in Flight Profile C by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

e. Vertical Error

The vertical error was calculated the same way as the horizontal error by squaring the time series data. All means are shown in the box plot below. This overview of the data shows potential outliers for the Day flights and Night 1 flights. The variance markedly decreases on Night 3. Since each profile had different characteristics, they will be analyzed separately.

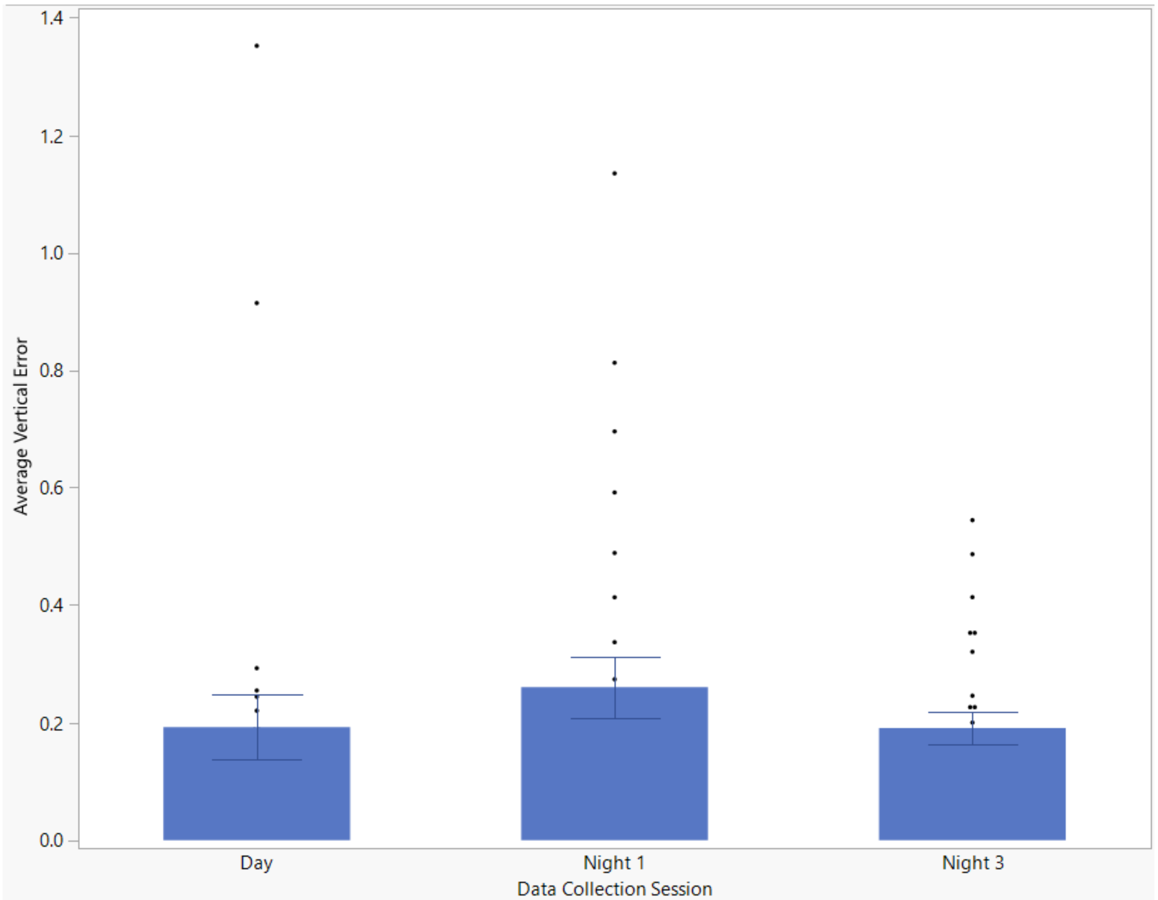

Figure 22. Average Vertical Error of All Participants and Flight Profiles. Vertical Lines Denote the Standard Error

(1) Profile A

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = .138, SD = 0.137), Night 1 (M = 0.101, SD = 0.066), and Day (M = 0.099, SD = 0.100) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.640$). Figure 23 shows average vertical error in flight profile A by data collection session (Day, Night 1, Night 3).

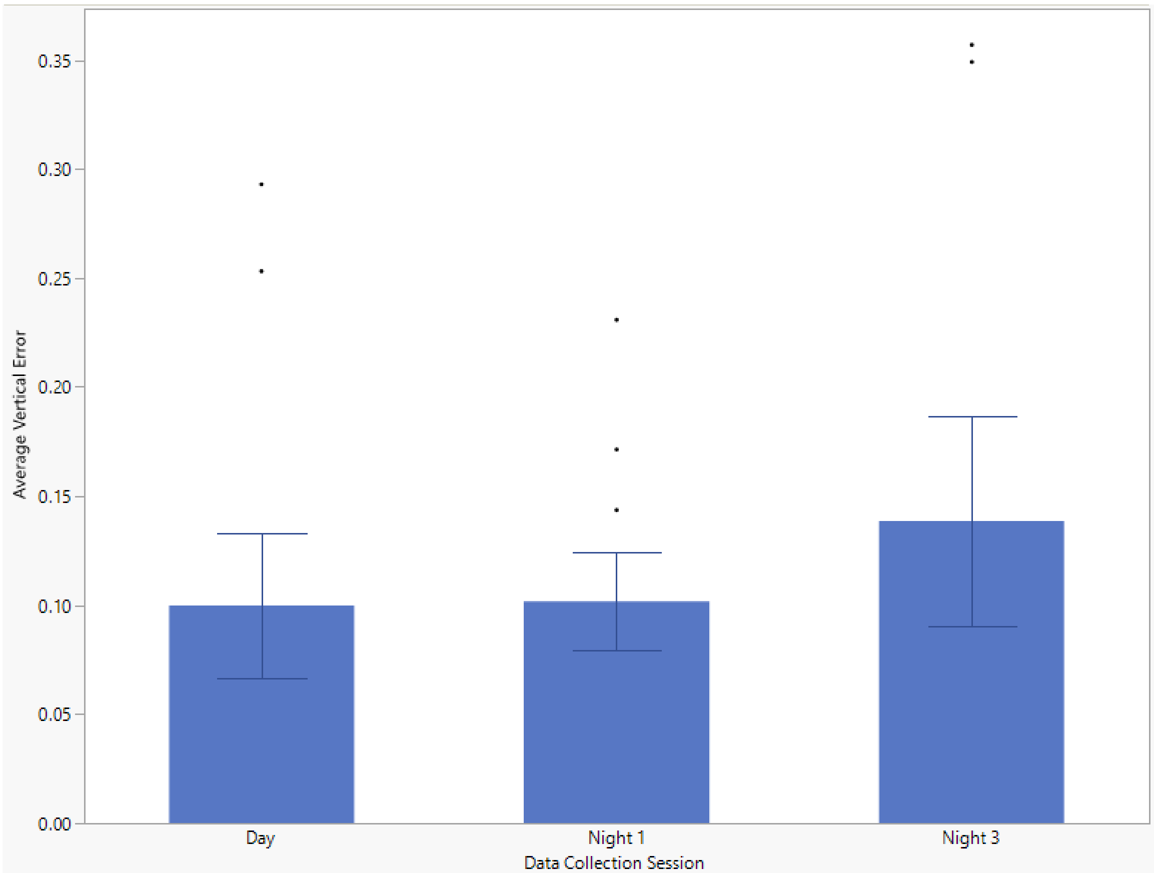

Figure 23. Average Vertical Error in Flight Profile A by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(2) Profile B

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 0.202, SD = 0.117), Night 1 (M = 0.333, SD = 0.357), and Day (M = 0.251, SD = 0.417) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.250$). Figure 24 shows average vertical error in flight profile B by data collection session (Day, Night 1, Night 3).

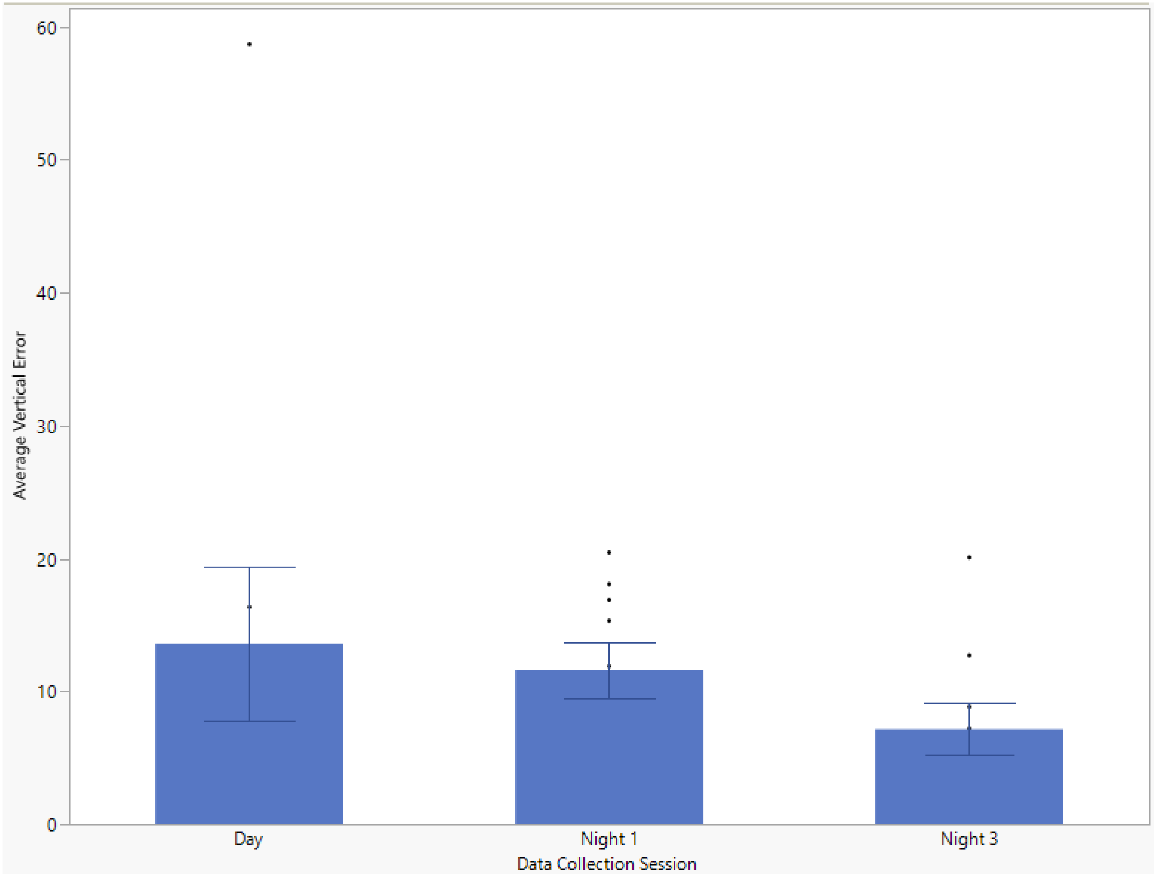

Figure 24. Average Vertical Error in Flight Profile B by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(3) Profile C

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 0.226, SD = 0.166), Night 1 (M = .346, SD = 0.251), and Day (M = 0.226, SD = 0.266) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.164$). Figure 25 shows average vertical error in flight profile C by data collection session (Day, Night 1, Night 3).

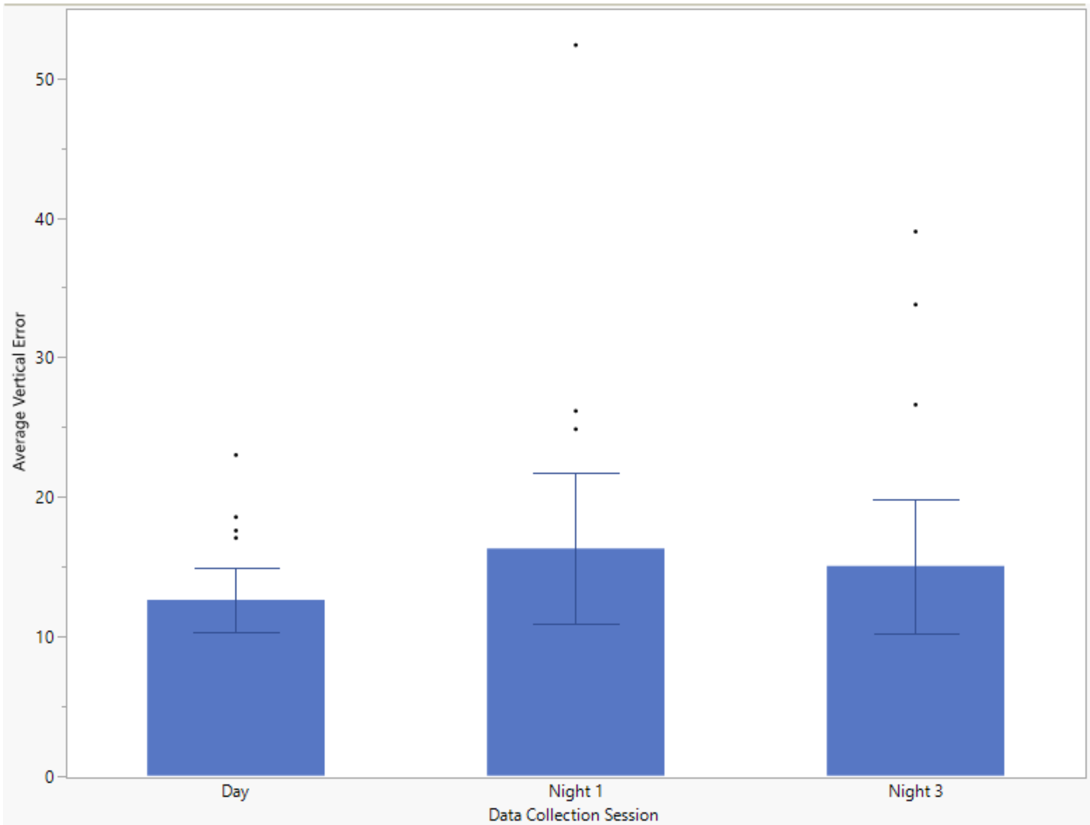

Figure 25. Average Vertical Error in Flight Profile C by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

f. Airspeed Error

The airspeed error is a measure of the participant's airspeed difference squared. This overview of the data shows the airspeed error was similar across all conditions.

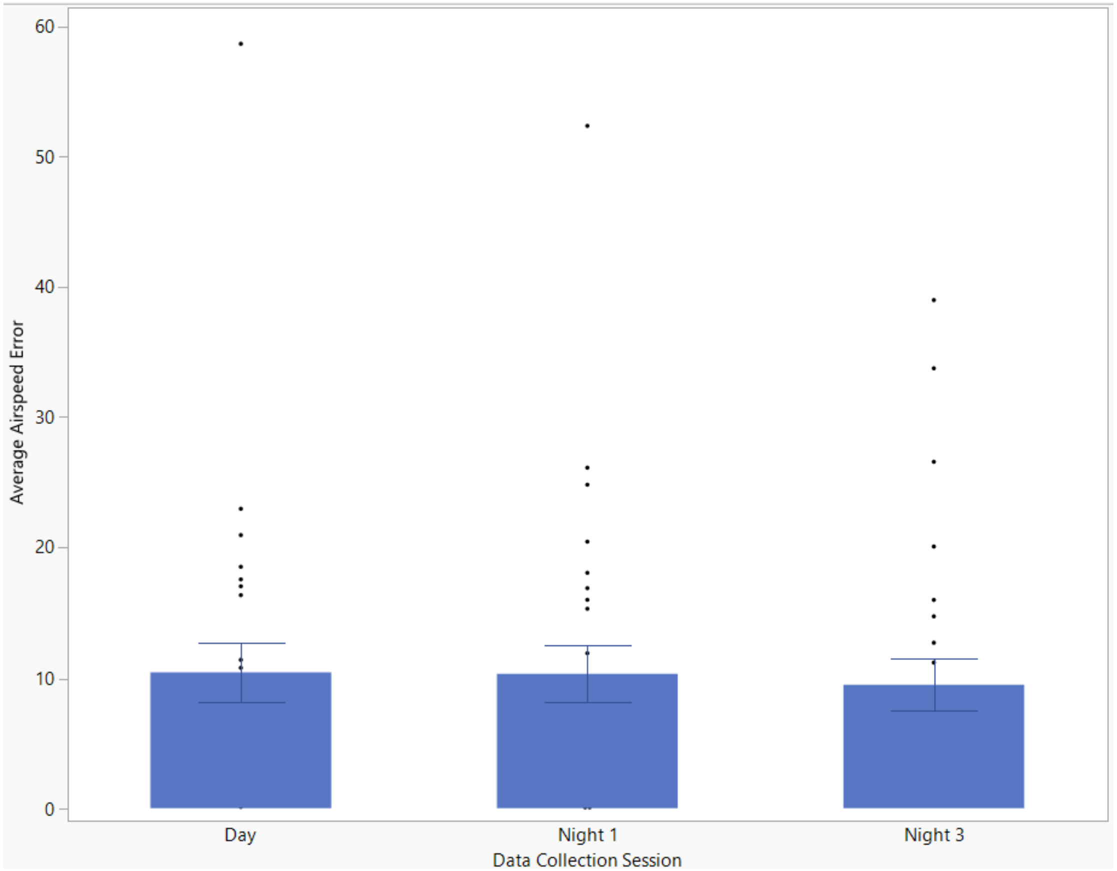

Figure 26. Average Airspeed Error of All Participants and Flight Profiles. Vertical Lines Denote the Standard Error

(1) Profile A

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 5.847, SD = 5.449), Night 1 (M = 3.027, SD = 2.928), and Day (M = 5.122, SD = 6.794) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.250$). Figure 27 shows average airspeed error in flight profile A by data collection session (Day, Night 1, Night 3).

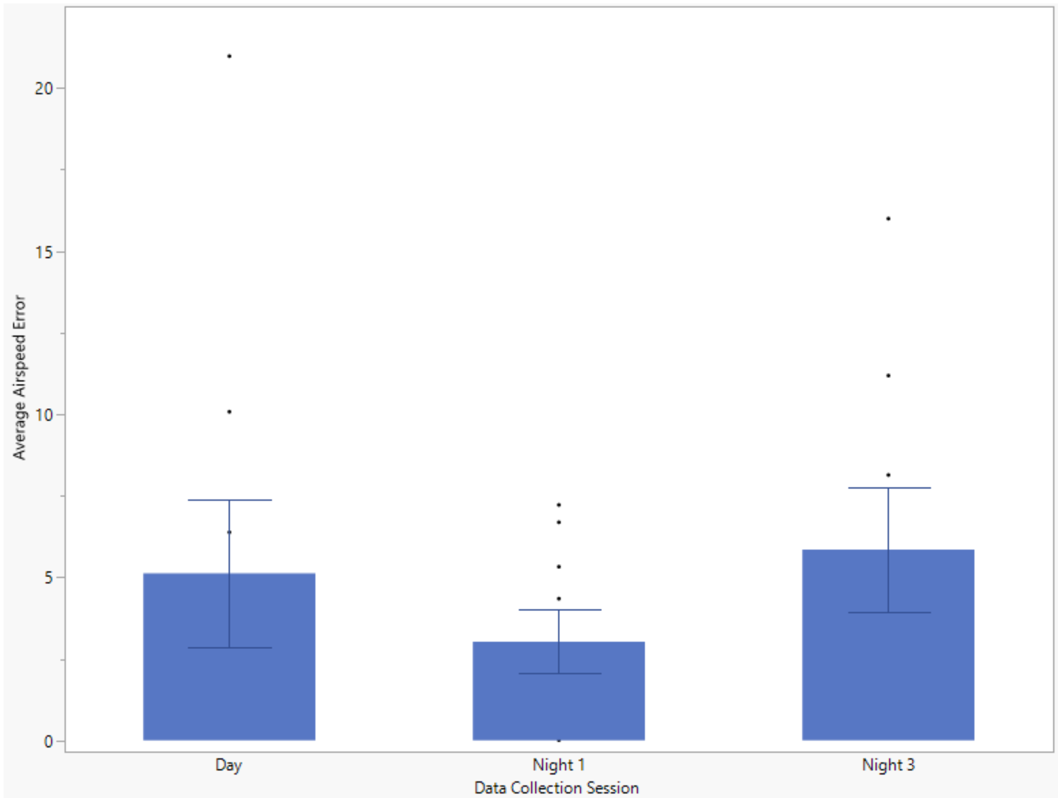

Figure 27. Average Airspeed Error in Flight Profile A by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(2) Profile B

Results showed that airspeed error differed between Night 3 (M = 7.180, SD = 5.960) and Night 1 (M = 11.605, SD = 6.393); Wilcoxon Signed Rank test, S = -16.5, p = 0.054). We did not identify any statistically significant differences between Day (M = 13.599, SD = 17.431) and Night 1 (M = 11.605, SD = 6.393), Night 3 (M = 7.180, SD = 5.960) and Day (M = 13.599, SD = 17.431); Wilcoxon signed rank test all $p > 0.300$). Figure 28 shows average airspeed error in flight profile B by data collection session (Day, Night 1, Night 3).

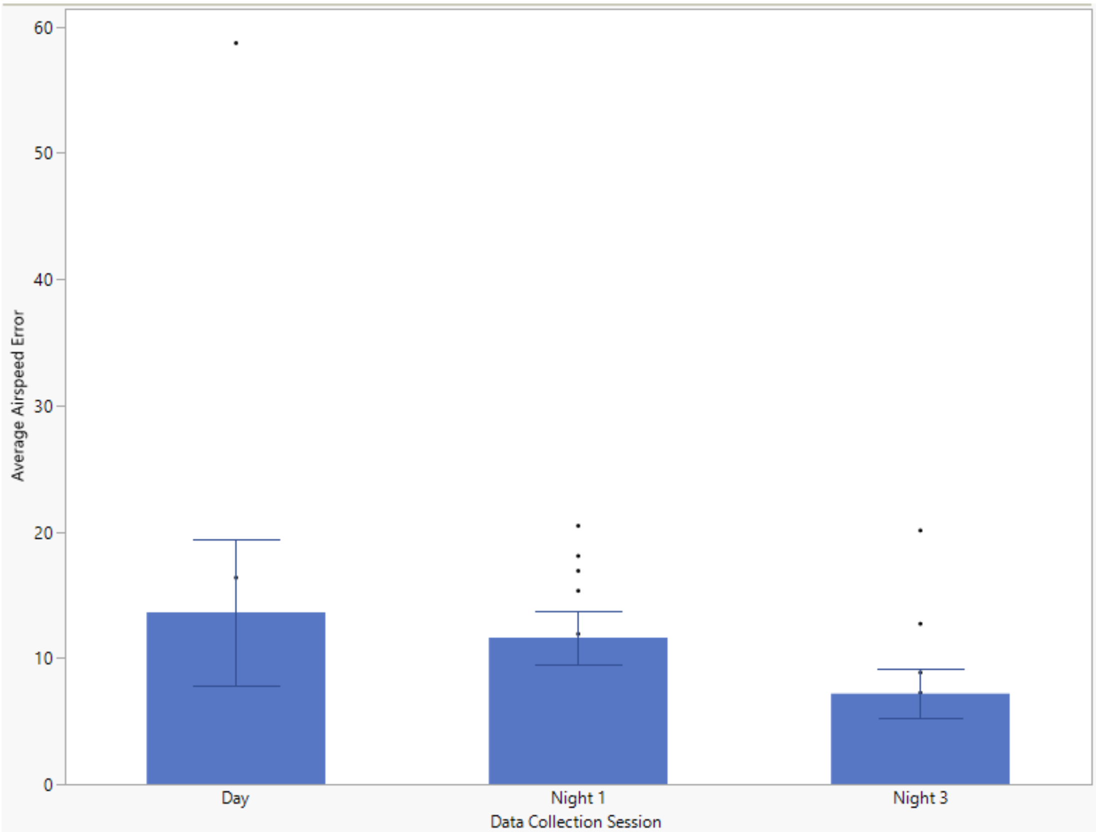

Figure 28. Average Airspeed Error in Flight Profile B by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

(3) Profile C

Based on pairwise comparisons, we did not identify any statistically significant differences among Night 3 (M = 15.023, SD = 14.399), Night 1 (M = 16.294, SD = 16.280), and Day (M = 12.590, SD = 6.812) data collection sessions (Wilcoxon Signed Rank test, all $p > 0.652$). Figure 29 shows average airspeed error in flight profile A by data collection session (Day, Night 1, Night 3).

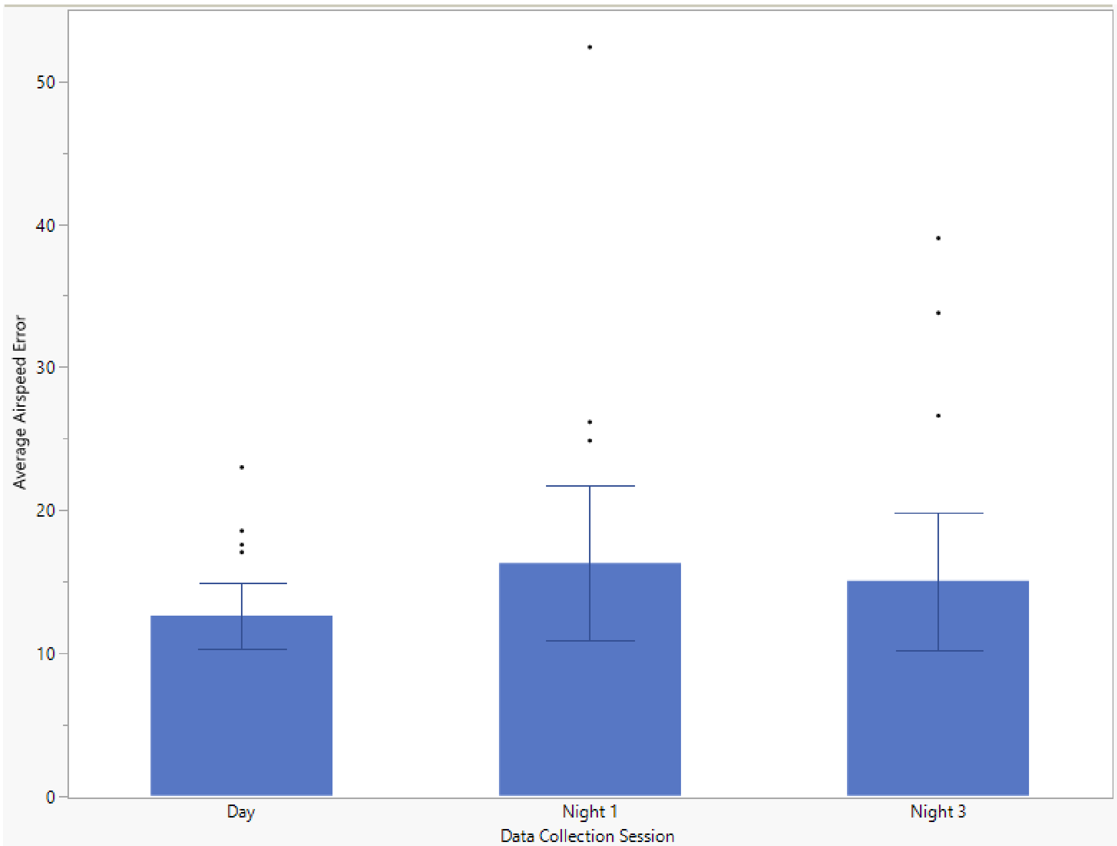

Figure 29. Average Airspeed Error in Flight Profile C by Data Collection Session (Day, Night 1, Night 3). Vertical Lines Denote the Standard Error

2. Overview of Findings Regarding Deflection, Airspeed Difference, and Error

The following tables show a consolidated overview of the findings we presented in the preceding paragraphs. A difference that is not statistically significant is denoted as "NSS." When a statistically significant difference exists, though, we show the trend. For example, in Profile A (Table 3) the absolute horizontal deflection in Night 1 is smaller than in the Day data collection session.

Table 3. Overview of Profile A Results

Performance metric	Night 3 vs. Night 1	Night 3 vs. Day	Night 1 vs. Day
Horizontal deflection	NSS (p = 0.460)	$\lvert Night\ 3 \rvert < \lvert Day \rvert$ (p = 0.039)	$\lvert Night\ 1 \rvert < \lvert Day \rvert$ (p = 0.015)
Vertical deflection	NSS (p = 0.148)	NSS (p = 0.945)	$\lvert Night\ 1 \rvert > \lvert Day \rvert$ (p = 0.023)
Airspeed difference	NSS (p = 0.843)	NSS (p = 0.843)	NSS (p = 0.250)
Horizontal error	NSS (p = 0.195)	NSS (p = 0.109)	$\lvert Night\ 1 \rvert < \lvert Day \rvert$ (p = 0.039)
Vertical error	NSS (p = 0.640)	NSS (p = 0.843)	NSS (p = 0.843)
Airspeed error	NSS (p = 0.460)	NSS (p = 0.640)	NSS (p = 0.742)

Table 4. Overview of Profile B Results

Performance metric	Night 3 vs. Night 1	Night 3 vs. Day	Night 1 vs. Day
Horizontal deflection	NSS (p = 0.570)	NSS (p = 0.652)	NSS (p = 0.652)
Vertical deflection	NSS (p = 0.300)	$\lvert Night\ 3 \rvert > \lvert Day \rvert$ (p = 0.054)	NSS (p = 0.425)
Airspeed difference	NSS (p = 0.250)	NSS (p = 0.652)	NSS (p = 0.496)
Horizontal error	NSS (p = 0.652)	NSS (p = 0.820)	NSS (p = 0.425)
Vertical error	NSS (p = 0.652)	NSS (p = 0.496)	NSS (p = 0.250)
Airspeed error	$\lvert Night\ 1 \rvert < \lvert Night\ 3 \rvert$ (p = 0.054)	NSS (p = 0.250)	NSS (p = 0.300)

Table 5. Overview of Profile C Results

Performance metric	Night 3 vs. Night 1	Night 3 vs. Day	Night 1 vs. Day
Horizontal deflection	NSS (p = 0.734)	NSS (p = 0.820)	NSS (p = 0.425)
Vertical deflection	NSS (p = 0.990)	$\lvert Night\ 3 \rvert < \lvert Day \rvert$ (p = 0.074)	NSS (p = 0.496)
Airspeed difference	NSS (p = 0.990)	NSS (p = 0.570)	NSS (p = 0.203)
Horizontal error	NSS (p = 0.734)	NSS (p = 0.570)	NSS (p = 0.990)
Vertical error	NSS (p = 0.203)	NSS (p = 0.570)	NSS (p = 0.164)
Airspeed error	NSS (p = 0.910)	NSS (p = 0.652)	NSS (p = 0.734)

B. PSYCHOMOTOR VIGILANCE TASK

A 3-minute PVT was conducted prior to the start of each profile. One final PVT was conducted at the end of the session. The averages for each of these PVT sessions can be found in Figure 30. Detailed information on PVT data can be found in Appendix D.

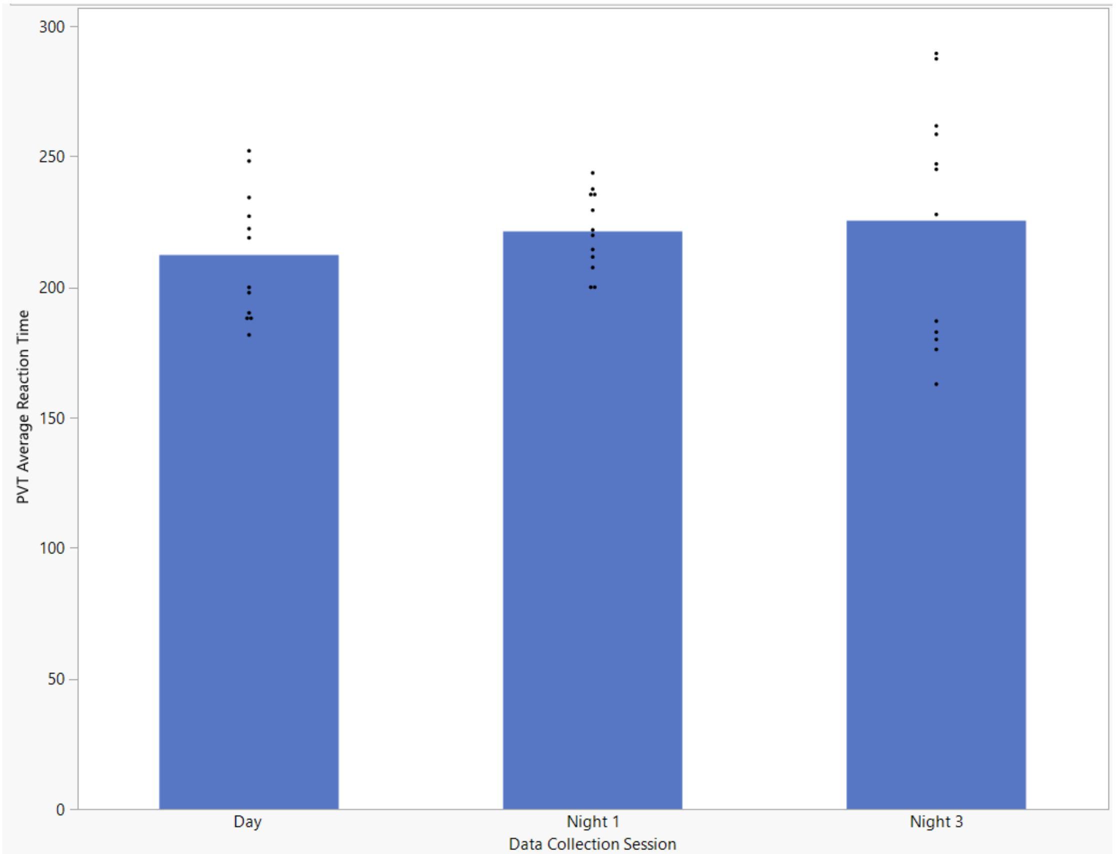

Figure 30. Average PVT Reaction Time for Participants 8, 9, and 10

We used pairwise analysis to determine any significant difference in the conditions (Day, Night 1, Night 3). No significant differences were found between Night 3 (M = 225.5, SD = 45.64), Night 1 (M = 221.3, SD = 14.88), and Day (M = 212.4, SD = 24.76); Wilcoxon Signed Rank test, all $p > 0.339$)

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V. DISCUSSION

A. CONCLUSIONS

This study was designed to assess the effectiveness of one night of HEV light treatment in shifting the DLMO of military aviators. This shift in DLMO was confirmed by the results published in Shattuck (2021). These results are in line with other studies in the field conducted using longer periods of light treatment (Lammers-van der Holst et al., 2021; Phillips et al., 2019).

In addition, this study assessed changes in performance that corresponded with the DLMO shift. We attempted to find a difference, first between pre- and post-treatment night flights (Night 1 and Night 3) and then between day and night flights (Day and Night 1). While we found some statistically significant results, none were consistent across all flight profiles.

There are several potential explanations of our findings. We believe the participants grew more used to the simulator and their performance may have improved due to training effect. We also had a sample size that was small enough to be highly influenced by outliers. Finally, the shift in our participants' circadian rhythms may not have been enough to see any change in the performance metrics we used. These factors could account for some of the inconsistent patterns in our data. We attempted to maximize the external validity of our study while still gaining verifiable results. We did not dictate any specific procedures regarding how each participant should maximize their performance. After each lab session, participants returned home just as they would at the end of a night flight. This serves to emphasize the influence of the light treatment despite outside complicating factors like sunlight to which they were exposed between the lab sessions. This also underlines the complexity of attempting to measure aviation performance with a simulator.

B. LIMITATIONS

1. Experimental Design

One of the major constraints on this study was the small sample size. The small sample size was due to a combination of factors. First, NPS has a limited number of personnel who have had previous tours in aviation. Second, the participants needed to devote a large amount of time to participate in the study and would feel the effects of the late nights they were required remain awake. There was no way to remove their academic obligations, even further reducing the number of personnel who could not participate due to schedule conflicts.

This limited number of available pilots precluded us from having enough participants for a control group, i.e., participants that would conduct the three night sessions in dim light without receiving the light treatment during the second night. Control groups have been used in similar studies (Duffy et al., 1996) and these control groups see a minimal shift in their circadian phase. However, these control groups were kept in darkness for much of the data collection time in a highly controlled environment.

The broad swath of experience covered by the participants was also a major limiting factor in the design of the study. The platform chosen for the simulator events and the events themselves tested a very limited aspect of aviation performance. We did not want to make these events too difficult for the participants who had been out of the cockpit for years. But we did not want to make the simulator scenarios so easy that all the participants could perform them without errors. There is also the potential that we may have overlooked errors by focusing on the wrong aspects of aviation performance.

2. Aviation Performance

In the current study, we used a light treatment of 1,000 lux for four hours. This light exposure resulted in the shift of all nine participants' circadian rhythm by 1.3 hours on average. The researchers thought these findings would be reflected in performance in an aircraft simulator. While confident that our subjects were fatigued for portions of the study, we did not see a corresponding drop in performance from that fatigue. This led us to rethink how fatigued aviation performance is measured.

In his dissertation, Taranto measured performance within a flight simulator by distance above or below glideslope and to the right or left of the centerline. Taranto was able to effectively show that novice pilots could greatly increase along this performance gradient with training (Taranto, 2020). This scoring system is straightforward and can be used to show both the benefits of automation and training within the model-based HSI realm. However, this scoring system was primarily used on subjects who had no prior military flight training. Additionally, it could not track state changes within subjects. The current study attempted to use this system for both of those aspects. However, we did not find a statistically significant change in pilot performance.

Taranto's work is also not without precedent. Caldwell, a leading aviation physiologist and researcher, conducted many influential sleep deprivation and aviation simulator studies 20 years ago, greatly advancing the field. He used methods similar to Taranto's with success (Caldwell et al., 2000). And somewhat analogously, studies on the effects of sleep deprivation and driving use similar performance indicators such as lane deviation, which is essentially a horizontal deflection (Liu et al., 2009; Thiffault & Bergeron, 2003). Finally, Belenky and his colleagues (2003) found a strong association between sleep deprivation and decreased reaction time. These studies and others were foundational to our research design. However, there were important aspects that we did not consider, specifically, participants' experience level, the mental functions needed to fly, and the root cause of fatigue-related aviation mishaps.

One of the reasons the current study may not have captured any performance-based fatigue indicators could be due to the level of expertise of the subject pool. This problem of expertise has been explored in the medical field with surgical performance. Gerdes and colleagues (2008) studied fatigue as it related to surgical performance. Their findings could have parallels with aviator performance. They used laparoscopic surgery simulators to obtain data from subjects' hand movements and cognitive errors. The subjects were tested both before and after their shifts and were split into two groups: attending surgeons with vast experience, and residents who were relatively new to the profession. The researchers found that the subjects performed similarly during the start of their shift. But when fatigued, the attending surgeons performed much better than the residents, making fewer cognitive errors (Gerdes et al., 2008). This finding suggests that experience may play a role in persistently good task performance despite fatigue. The current study was made up of relatively proficient pilots and that proficiency may have blunted the effects of fatigue on the performance measures.

The results of the study conducted by Gerdes and colleagues can be related to other cognitively demanding jobs. Experts in a field could be unconsciously developing strategies for operating in a cognitively degraded state. A study by Phillips (2014) sheds light on the relationship between operator fatigue and performance. One of Phillips' conclusions was that there is not necessarily a direct link between an operator's energy level and performance degradation. There are multiple factors at work such as attitude, motivation, and strategies that operators use when becoming fatigued. Also, isolating task fatigue, homeostatic fatigue, and circadian fatigue's effect on performance in the lab setting is difficult (Phillips, 2014). These two studies suggest that the current study simply may not have gotten an effect large enough for it to be captured by the performance metrics. Possible reasons for this could be that the simulator scenarios were not difficult enough, the participants may not have been sufficiently fatigued, or the researchers may have used the wrong performance metrics.

Baker and colleagues (2008) conducted an archival study of aviation mishaps from 1983 to 2002. Not only did they look at the rate of increase and decrease of types of accidents, but they also looked at the overall proportions of causal factors of these mishaps across the board. They found that only 20% of these mishaps were due to kinetic mishandling of the aircraft, which is primarily what the current study was testing. Kinetic mishandling may be the most straightforward way to judge performance, but it is not the most common way pilots falter in operational environments. The other major contributing factors cited by Baker were carelessness, flawed decision making, poor crew interaction, or mishandled wind/runway conditions (Baker et al., 2008). It is much harder to investigate these types of errors, but if they are not studied, researchers miss the opportunity to discover new ways to mitigate aviation mishaps.

It is also important to note that the factors listed in a mishap investigation come from the self-assessment of personnel involved in the incident. Asking people to assess their own fatigue level can be misleading. A study conducted on surgeons investigated self-awareness of fatigue. Berastegui and colleagues (2020), again focused on physicians, used psychomotor vigilance tasks as an objective measure of fatigue throughout medical shifts and the Karolinska Sleepiness Scale (KSS) as a subjective measurement. Twenty-eight physicians participated in the study. The investigators found that KSS scores remained relatively stable over time while reaction time slowly worsened. Their findings confirmed the conclusions of other studies that humans are generally poor at assessing their sleepiness. As most mishap investigations rely on user reports to determine causal factors, fatigue may be underreported because of the aircrew's subjective assessment.

Naval Safety Center researchers Dunning and Kelly (2020), investigated this particular discrepancy in the post hoc analysis of Naval aviation mishap data. In their report, they discuss 10 fatigue-related symptoms that are documented in post mishap interviews. These factors include not paying attention, confusion, distraction, life stressors, emotional state, complacency, motivation, mental exhaustion, misperception of changing environment, and misinterpreted/misread instruments. At the time of the mishaps being investigated, investigators did not relate these symptoms to fatigue, because aircrew members did not specifically report they were fatigued. As discussed, subjective assessment of fatigue is a poor way of measuring its prevalence. An exploration of aviation-related fatigue needs to assess the effects that fatigue has on these higher cognitive processes such as decision making, memory, and motivation. The sole focus cannot be the kinetic manipulation of the aircraft.

After all, in the investigation of the December 6th mishap that spawned the current study, the contributing factors had little to do with the poor flying of the aircraft. The pilot was able to conduct aerial refueling, a notably difficult aviation maneuver. It was after successful refueling that the contributing factors of the mishap come into play: flying in formation on the non-standard side of the tanker aircraft, using the wrong lighting configuration, and not clearing in the direction of the turn (Thomas, 2018).

To have internally valid results, a performance study needs verifiable tests that have been vetted thoroughly in previous studies. However, the current study focused specifically on aviation performance. If the study is to be relevant to aviation, it also needs tasks that can be externally valid, i.e., related to the functions performed while actually flying an aircraft. Specifically, it should focus on those functions that are not performed correctly resulting in mishaps. While the decision-making aspects of performance related to fatigue have not been the focus of study within the flight community, the medical community has done considerable research on higher cognitive function, performance, and fatigue.

Barker and Nussbaum (2011) conducted a study focusing on errors in nursing work. Participants for this study completed simulated nursing tasks that had both high and low levels of workload. The researchers used several measures to assess both mental and physical fatigue. In the current study, the physical performance measures served little purpose because the dexterity and visual tasks relate closely to what the participants had already done in the flight simulator. However, Barker and Nussbaum used a measure to test the mental fitness of their participants in addition to their physical performance. The mental performance measurement battery used was the Automated Neuropsychological Metrics (ANAM) test battery, which was developed by U.S. Army Medicine to assess soldiers with mild traumatic brain injuries. The U.S. Army describes the ANAM as a "computer-based tool designed to detect speed and accuracy of attention, memory, and thinking ability" (Army Neurocognitive Assessment Branch, 2016). It could potentially serve to evaluate higher cognitive functions in the case of flight performance.

The ANAM has also been used by researchers at Johns Hopkins Applied Physics Laboratory to assess decision-making performance. McKneely and her team (2006) researched situational awareness in military command and control using parts of the ANAM as their performance measures. Participants in this study were asked to complete several different tasks in a situational awareness scenario along with the ANAM. The results from this study did not show a major difference in sleepiness and the ANAM showed an increase in math speed and accuracy as the subjects had less sleep. The authors postulated that since the subjects were engineering students the math might be helping to keep them awake. This propensity for math is a potential confounding factor to consider if future studies were to use this assessment on military aviators, which is also a math-intensive occupation.

Math calculations have been used to assess astronaut performance. Eddy and colleagues (1998) gave astronauts spending an extended period in space multiple tests both before flight and while the astronauts were in orbit. Researchers saw a decrease in math performance as the flight continued. The sample size for this particular experiment was necessarily small as there were only four astronauts on the study flight. And while the astronauts reported being fatigued there were no formal measures to correlate that subjective reporting.

In addition to math computational tasks, McKneely and colleagues (2006) used the psychomotor vigilance task (PVT) in their study on situational awareness. It was an excellent predictor of fatigue. This finding agrees with the prevailing literature on fatigue assessment. The PVT assesses a subject's reaction time and how that corresponds to other physiological indicators showing a subject's fatigue. PVT does not directly measure the executive allocation of cognitive resources that are associated with decision making and risk management. Tucker and colleagues (2010) attempted to differentiate the attention degradation associated with PVT and other executive functions. They were able to show a decrease in PVT performance that corresponded with fatigue. But the primary purpose of the study was to separate the factors of cognitive performance from executive function tasks that rely on reaction time. Tucker et al. believed that the decrease in performance that has been commonly associated with a degradation of executive function can be explained by the attention degradation and its snowball effect on other cognitive functions.

Causse and colleagues (2011) investigated the role of executive functions in aviation, but focused primarily on how age degraded executive function, not fatigue. They developed a test battery that included the PVT, the 2-back test, and the computerized Wisconsin Card Sorting test. Each of these tests is designed to test a certain aspect of cognitive function that they then related to a specific aviation task. These aviation tasks were more focused on the processes that aviators follow and the decisions they make, rather than their ability to control the aircraft. Their experimental design could be modified to introduce fatigue as an independent variable allowing researchers to further solidify the relationship between these specific cognitive tests and aviation tasks.

To understand what role fatigue plays in aviation mishaps, we first need to make the connection between fatigue and how it affects aspects of our thinking. We have seen in previous research that fatigue affects certain parts of our brain related to executive function. We have also seen that one is usually inaccurate when self-assessing fatigue levels. This presents a problem in how fatigue is measured in the aviation community. We do not have a full grasp of how it affects aviation performance, and most mishap investigations rely on self-assessment. We need to connect how we think in a fatigued state to the functions performed while flying. More specifically, we need to focus on those functions that are more likely to result in mishaps. A longitudinal study of aviation mishaps shows that there are more factors to a mishap than simply the kinetic movement of the aircraft. Up until this point, we have been primarily measuring fatigue degraded performance through kinetic movement, which, ultimately, will not suffice. Measuring fatigue in aviation is not as straightforward as we had expected. But we now have a better understanding of the relevant performance factors in flight and this information can be used to work towards better ensuring the safety of military aviators and potentially saving lives.

VI. RECOMMENDATIONS

This study highlights the potency of light to entrain circadian rhythms. The results of the shift in DLMO for all participants (M = 1 h 19 m ± 22 m) (McDonough, 2021; Shattuck et al., 2021) illustrated what one night of light treatment could do to shift circadian rhythms. However, this study was limited in many ways and much needs to be assessed before this can become a viable operational tool.

First, follow-on studies should draw participants from a population of operational aviators, especially if they are qualified in the same platform. Many of the limitations in the simulator scenarios and the performance metrics came from having participants with a broad range of experience, both in type of aircraft and hours flown. Additionally, participants in the current study were stationed at non-flying billets. They were not able to maintain their flying skills. The simulator scenarios designed for this study had to be general and straightforward enough for all participants to complete. If follow-on studies use operational aviators, the simulator scenarios can be specifically tailored to their advanced skill level and to their flight platform.

Additionally, the use of the simulator in assessing performance would need to go beyond the kinetic performance of the aviator, i.e., the ability to maintain course, airspeed, and altitude. To truly operationalize aviation performance, researchers need to include other aspects of cognitive function used in aviation, to include decision-making, short-term memory, and risk management. There are cognitive tests that can assess these aspects of cognition. They need to be assessed in conjunction with related cognitive performance in simulator scenarios.

Finally, this study was only able to conduct a light treatment over one night. To better assess the effect of light treatment, follow-on studies should focus on treating over multiple nights looking for a greater DLMO shift. In reviewing the literature, we saw the effect of light treatment over multiple nights in further shifting individuals and in better establishing circadian entrainment (Duffy et al., 1996; Lammers-van der Holst et al., 2021; Phillips et al., 2019). This effect needs to be tested using aviators adjusting to a night flying schedule to provide a more externally valid assessment of its benefit to the aviation community.

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APPENDIX A. SURVEYS

Enrollment Questionnaire

Instructions: *Please answer ALL questions as accurately as possible. ALL information is confidential and will be used only for research purposes.*

Table 6. What is your age: _______________ years

1. What is your sex (Check one ☑) ☐ Male ☐ Female

1. What is your branch of service? ________________________________

1. What is your rank: ________________________________

1. Have you piloted an aircraft in the last 12 months? (Check one ☑) ☐ Yes ☐ No

1. Which aircraft have you flown? ________________________________

Table 1. Approximately how many total flight hours do you have? ________________________________

- How many hours have you flown in your primary aircraft?

____

1. Do you habitually use nicotine products? (Check one ☑)
☐ Yes ☐ No

If **YES**, please indicate which products you use, and how often you use them:

☐♟ Cigarettes ______________ Times per week
☐♟ Chewing tobacco/snuff ______________ Times per week
☐♟ Nicorette gum or patches ______________ Times per week
☐♟ Electronic smoke ______________ Times per week
☐♟ Other (specify): _________________ ______________ Times per week

1. How many of the following caffeinated beverages do you drink **on average** each day?

(Check ALL that apply ☑) and indicate daily amount)

☐ Tea	Servings/Cups per day: _______________
☐ Coffee	Servings/Cups per day: ________
☐ Soda/pop/soft drinks	Servings/Cups per day: ________
☐ Energy drinks (Monster/ RedBull, etc.)	Servings/Cups per day: ________
☐ Other (specify): __________________	How often: ________ (Example: 4 times per day)

1. Do you take any prescribed or over-the-counter medications? (Check one ☑) ☐ Yes ☐ No

If **YES**, please list all medications you take:

____
____

____
____

1. Have you ever been diagnosed with a sleep-related disorder?
☐ Yes ☐ No

If YES, please describe:
____

M-E Instructions: *For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.*

1. Approximately what time would you get up if you were entirely free to plan your day?

[5] 5:00 AM–6:30 AM (05:00–06:30 h)	[4] 6:30 AM–7:45 AM (06:30–07:45 h)	[3] 7:45 AM–9:45 AM (07:45–09:45 h)	[2] 9:45 AM–11:00 AM (09:45–11:00 h)	[1] 11:00 AM–12 noon (11:00–12:00 h)
☐	☐	☐	☐	☐

2. Approximately what time would you go to bed if you were entirely free to plan your evening?

[5] 8:00 PM–9:00 PM (20:00–21:00 h)	[4] 9:00 PM–10:15 PM (21:00–22:15 h)	[3] 10:15 PM–12:30 AM (22:15–00:30 h)	[2] 12:30 AM–1:45 AM (00:30–01:45 h)	[1] 1:45 AM–3:00 AM (01:45–03:00 h)
☐	☐	☐	☐	☐

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

[4] Not at all	[3] Slightly	[2] Somewhat	[1] Very much
☐	☐	☐	☐

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?

[1] Very difficult	[2] Somewhat difficult	[3] Fairly easy	[4] Very easy
☐	☐	☐	☐

5. How alert do you feel during the first half hour after you wake up in the morning?

[1] Not at all	[2] Slightly alert	[3] Fairly alert	[4] Very alert
☐	☐	☐	☐

6. How hungry do you feel during the first half hour after you wake up?

[1] Not at all hungry	[2] Slightly hungry	[3] Fairly hungry	[4] Very hungry
☐	☐	☐	☐

7. During the first half hour after you wake up in the morning, how do you feel?

[1] Very tired	[2] Fairly tired	[3] Fairly refreshed	[4] Very refreshed
☐	☐	☐	☐

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

[4] Seldom or never later	[3] Less than1 hour later	[2] 1–2 hours later	[1] More than 2 hours later
☐	☐	☐	☐

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7–8 AM (07-08 h). Bearing in mind nothing but your own internal "clock," how do you think you would perform?

[4] Would be in good form	[3] Would be in reasonable form	[2] Would find it difficult	[1] Would find it very difficult
☐	☐	☐	☐

10. At approximately what time in the evening do you feel tired, and, as a result, in need of sleep?

[5] 8:00 PM–9:00 PM (20:00–21:00 h)	[4] 9:00 PM–10:15 PM (21:00–22:15 h)	[3] 10:15 PM–12:45 AM (22:15–00:45 h)	[2] 12:45 AM–2:00 AM (00:45–02:00 h)	[1] 2:00 AM–3:00 AM (02:00–03:00 h)

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?

[6] 8 AM–10 AM (08–10 h)	[4] 11 AM–1 PM (11–13 h)	[2] 3 PM–5 PM (15–17 h)	[0] 7 PM–9 PM (19–21 h)

12. If you got into bed at 11 PM (23 h), how tired would you be?

[0] Not at all tired	[2] A little tired	[3] Fairly tired	[5] Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

[4] Will wake up at usual time, but will not fall back asleep	[3] Will wake up at usual time and will doze thereafter	[2] Will wake up at usual time, but will fall asleep again	[1] Will not wake up until later than usual

14. One night you have to remain awake between 4–6 AM (04-06 h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

[1] Would not go to bed until the watch is over	[2] Would take a nap before and sleep after	[3] Would take a good sleep before and nap after	[4] Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?

[4] 8 AM–10 AM (08–10 h)	[3] 11 AM–1 PM (11–13 h)	[2] 3 PM–5 PM (15–17 h)	[1] 7 PM–9 PM (19–21 h)

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10–11 PM (22-23 h). Bearing in mind only your internal "clock," how well do you think you would perform?

[1] Would be in good form	[2] Would be in reasonable form	[3] Would find it difficult	[4] Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?

[5] 5 hours starting between 4–8 AM (05–08 h)	[4] 5 hours starting between 8–9 AM (08–09 h)	[3] 5 hours starting between 9 AM–2 PM (09–14 h)	[2] 5 hours starting between 2–5 PM (14–17 h)	[1] 5 hours starting between 5 PM–4 AM (17–04 h)

18. At approximately what time of day do you usually feel your best?

[5] 5–8 AM (05–08 h)	[4] 8–10 AM (08–10 h)	[3] 10 AM–5 PM (10–17 h)	[2] 5–10 PM (17–22 h)	[1] 10 PM–5 AM (22–05 h)
☐	☐	☐	☐	☐

19. One hears about “morning types” and “evening types.” Which one of these types do you consider yourself to be?

[6] Definitely a morning type	[4] Rather more a morning type than an evening type	[2] Rather more an evening type than a morning type	[1] Definitely an evening type
☐	☐	☐	☐

Morningness-Eveningness survey (Adan & Almirall, 1991).

Pre-flight Questionnaire

ESS instructions: *How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in the **last week**. Even if you have not done some of these things recently try to work out how they would have affected you. Check ☑ the most appropriate number for each situation.*

	CHANCE OF DOZING			
	None (0)	Slight (1)	Moderate (2)	High (3)
Sitting and reading	○	○	○	○
Watching TV	○	○	○	○
Sitting inactive in a public place (e.g., a theater or a meeting)	○	○	○	○
As a passenger in a car for an hour without a break	○	○	○	○
Lying down to rest in the afternoon when circumstances permit	○	○	○	○
Sitting and talking to someone	○	○	○	○
Sitting quietly after a lunch without alcohol	○	○	○	○
In a car, while stopped for a few minutes in traffic	○	○	○	○

Karolinska Sleepiness Scale Assessment

KSS Instructions: *Here are some descriptors about how alert or sleepy you might be feeling right now. Please read them carefully and CIRCLE the number that best corresponds to the statement describing how you feel at the moment.*

1. Extremely alert
2. Very alert
3. Alert
4. Rather alert
5. Neither alert nor sleepy
6. Some signs of sleepiness
7. Sleepy, no effort to stay awake
8. Sleepy, some effort to stay awake
9. Very sleepy, great effort to keep awake, fighting sleep

PSQI instructions: *The following questions relate to your usual sleep habits during the **last week <u>only</u>**. Your answers should indicate the most accurate reply for the <u>majority</u> of days/nights in the **last week**. Please answer all questions.*

1. In the last week, what time have you usually gone to bed at night?	Bed Time: _______________
a. During the last week, how long (in minutes) has it usually taken you to fall asleep each night	Number of Minutes:________
- In the last week, what time have you usually gotten up in the morning?	Getting up time:___________
- During the last week, how many hours of <u>actual sleep</u> did you get at night? (this may be different than the number of hours you spent in bed.)	Hours of Sleep per Night:__

Instructions: *For each of the questions, check the one best response.*

- During the last week, how often have you had trouble sleeping because you…	Not during the past month	Less than once a week	Once or twice a week	3 or more times a week
I. Cannot get to sleep within 30 mins	○	○	○	○
I. Wake up in the middle of the night or early morning	○	○	○	○
• Have to get up to use the bathroom	○	○	○	○
I. Cannot breathe comfortably	○	○	○	○
1. Cough or snore loudly	○	○	○	○
a. Feel too cold	○	○	○	○
- Feel too hot	○	○	○	○
a. Had bad dreams	○	○	○	○
• Have pain	○	○	○	○

VII. Other reason(s), please describe: ______________________________ How often during the last week have you had trouble sleeping because of this other reason?	○	○	○	○
1. During the last week, how would you rate your sleep quality overall?	Very Good ○	Fairly Good ○	Fairly Bad ○	Very Bad ○
1. During the last week, how often have you taken medicine to help you sleep (prescribed or "over the counter"?	Not during the past week ○	Less than once a week ○	Once or twice a week ○	Three or more times a week ○
1. During the last week, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	○	○	○	○
1. During the last week, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	Not a problem at all	Only a very slight problem	Somewhat of a problem	A very big problem

Epworth Sleepiness Scale and Pittsburgh Sleep Quality Index (Nishiyama et al., 2014).
Karolinska Sleepiness Scale (Akerstedt et al., 1990)

ARRIVAL CHECKLIST

To be completed by the researcher.

If you are unsure if you should proceed with the study activities for any reason, contact Dr. Nita Shattuck at (831) 277–8080.

Participant ID: ____________

Date: ___________________

Arrival time: _____________

Orientation Brief:

Welcome Participant to the lab. Go over the night number and light type.

Maintain light discipline: "Stay behind taped line, if you need anything a researcher will be within earshot. The researcher will give you goggles and escort you to the bathroom."

Ensure you do these things to get good melatonin samples: "Snack only after the sample is weighed on the top of the hour, stop drinking water and remain seated 5 min before taking a melatonin sample."

Time of last meal: __________________

If more than 4 hours, contact Dr. Shattuck.

Time of last caffeine: __________________

If less than 4 hours, contact Dr. Shattuck.

1. Are you feeling well and healthy today? ☐**Yes** ☐ **No**

If no, contact Dr. Shattuck.

1. Did you maintain your assigned sleep schedule? ☐**Yes** ☐ **No**

If no, contact Dr. Shattuck. *Download the actigraph to confirm.*

1. Have you taken any over-the-counter medications or supplements today? ☐**Yes** ☐ **No**

If yes, what medications? ___________________________

If yes, contact Dr. Shattuck.

1. Have you arranged a ride home for after the study? ☐**Yes** ☐ **No**

If no, please arrange your ride home now.

Sample instructions:

-5 minutes out, "swish and swallow with water, refrain from drinking or eating for the next five minutes, remain seated with feet flat on the floor"

-Sample collection:

verify number on top of sample and on label

"Pour the dental swab into your mouth, do not chew on it."

Time for 1 minute.

"Spit swab into tube, top of tube with any extra saliva"

weigh tube if less than 8.7 retest with second tube, if between 8.7 and 8.9 spit to top off, if above 9.0 participant is complete.

During Flight Assessment:

Bedford Workload Scale

Time:____________

BWS Instructions: *Below is a decision tree and descriptors about your workload. Please read them carefully and CIRCLE the number that best corresponds to the statement describing your workload.*

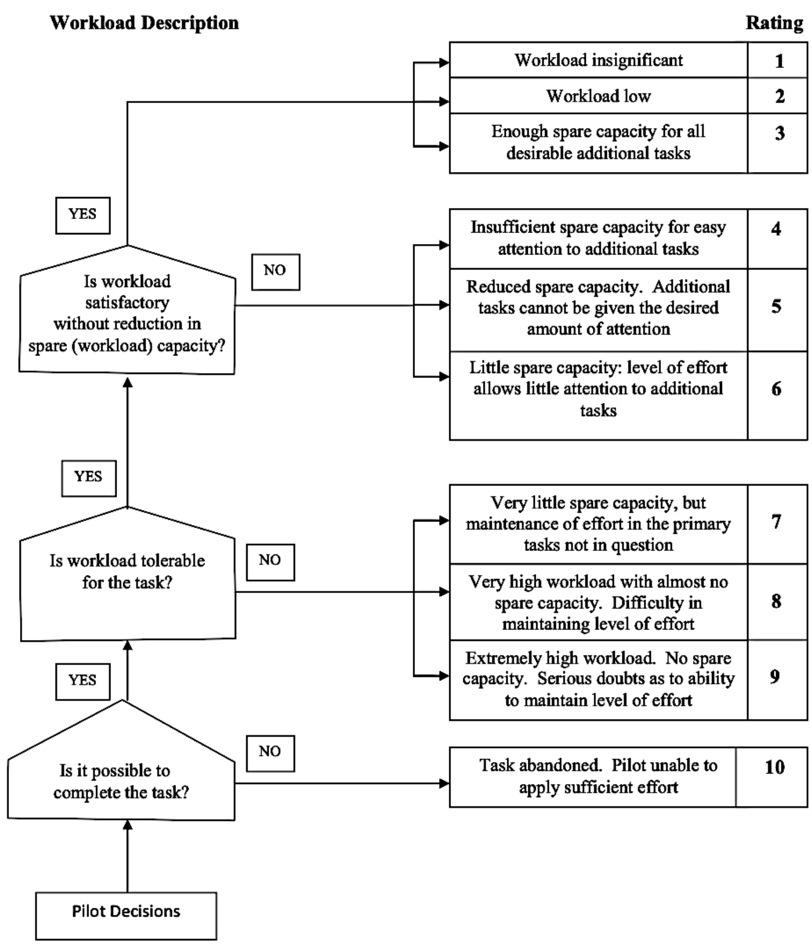

Figure 1. Bedford Workload Rating Scale.

Bedford Workload Scale (Roscoe & Ellis, 1990)

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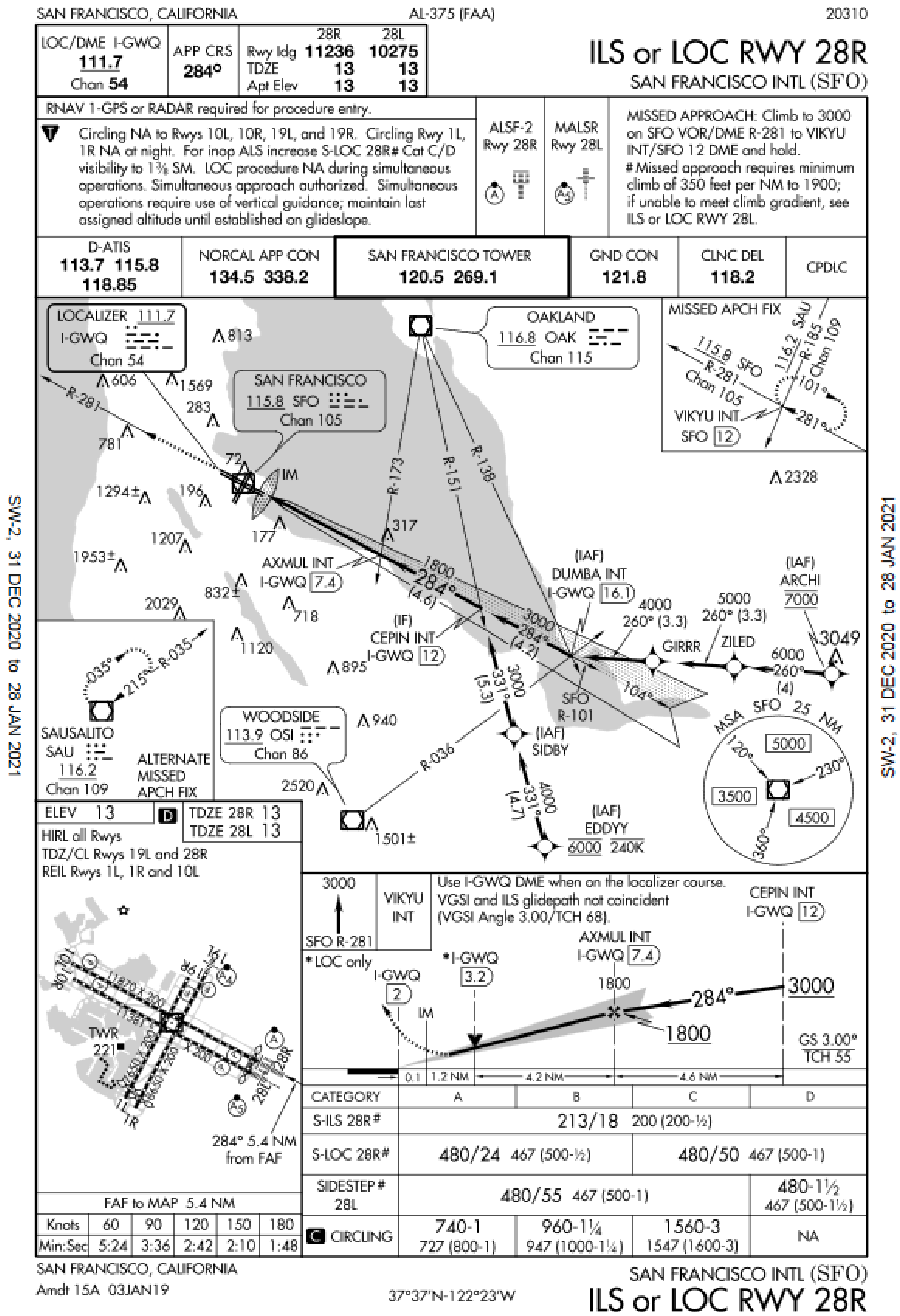
APPENDIX B. APPROACH PLATES



CATEGORY	A	B	C	D
S-ILS 28R#	213/18 200 (200-½)			
S-LOC 28R#	480/24 467 (500-½)		480/50 467 (500-1)	
SIDESTEP# 28L	480/55 467 (500-1)			480-1½ 467 (500-1½)
CIRCLING	740-1 727 (800-1)	960-1¼ 947 (1000-1¼)	1560-3 1547 (1600-3)	NA

FAF to MAP 5.4 NM

Knots	60	90	120	150	180
Min:Sec	5:24	3:36	2:42	2:10	1:48

ILS or LOC RWY 1L
MC CARRAN INTL (LAS)

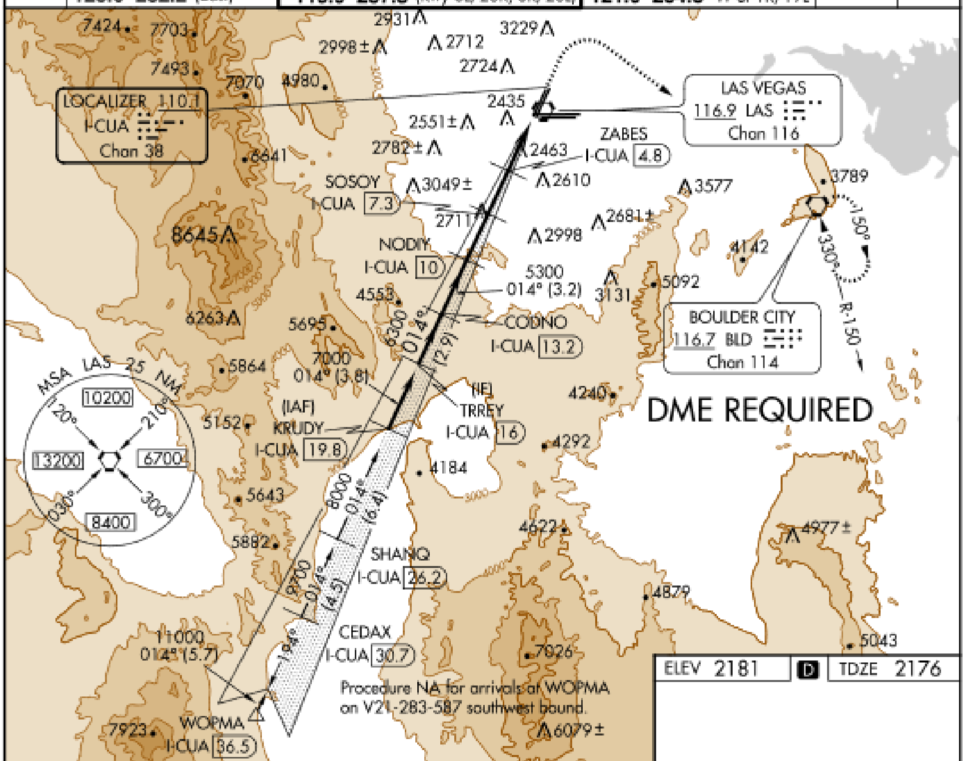
LOC/DME I-CUA 110.1 Chan 38	APP CRS 014°	Rwy ldg 8401 TDZE 2176 Apt Elev 2181

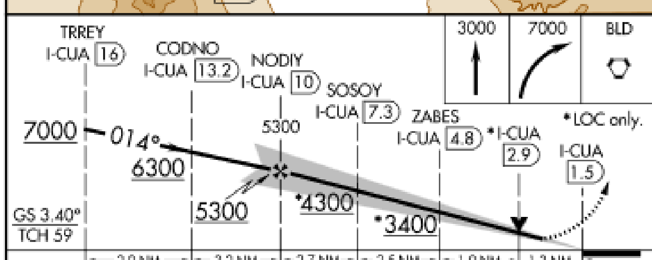
Rwy 1L helicopter visibility reduction below ¾ SM NA.
DME required.
For inop ALS, increase S-ILS 1L all Cats visibility to ⅞ SM.

MALSF

MISSED APPROACH: Climb to 3000 then climbing right turn to 7000 direct BLD VORTAC and hold, continue climb-in-hold to 7000.

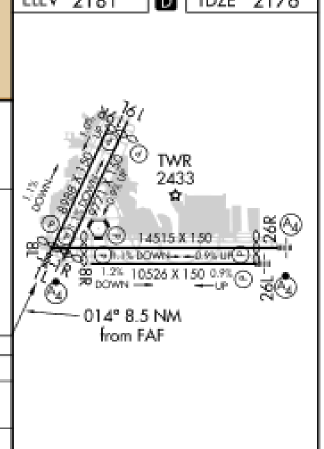
D-ATIS	LAS VEGAS APP CON	LAS VEGAS TOWER	GND CON	CLNC DEL	CPDLC
132.4	125.025 379.15 (West) 125.6 282.2 (East)	118.75 257.8 (Rwy 1L/19R, 1R/19L) 119.9 257.8 (Rwy 8L/26R, 8R/26L)	121.1 270.8 E of 1R/19L 121.9 254.3 W of 1R/19L	118.0	





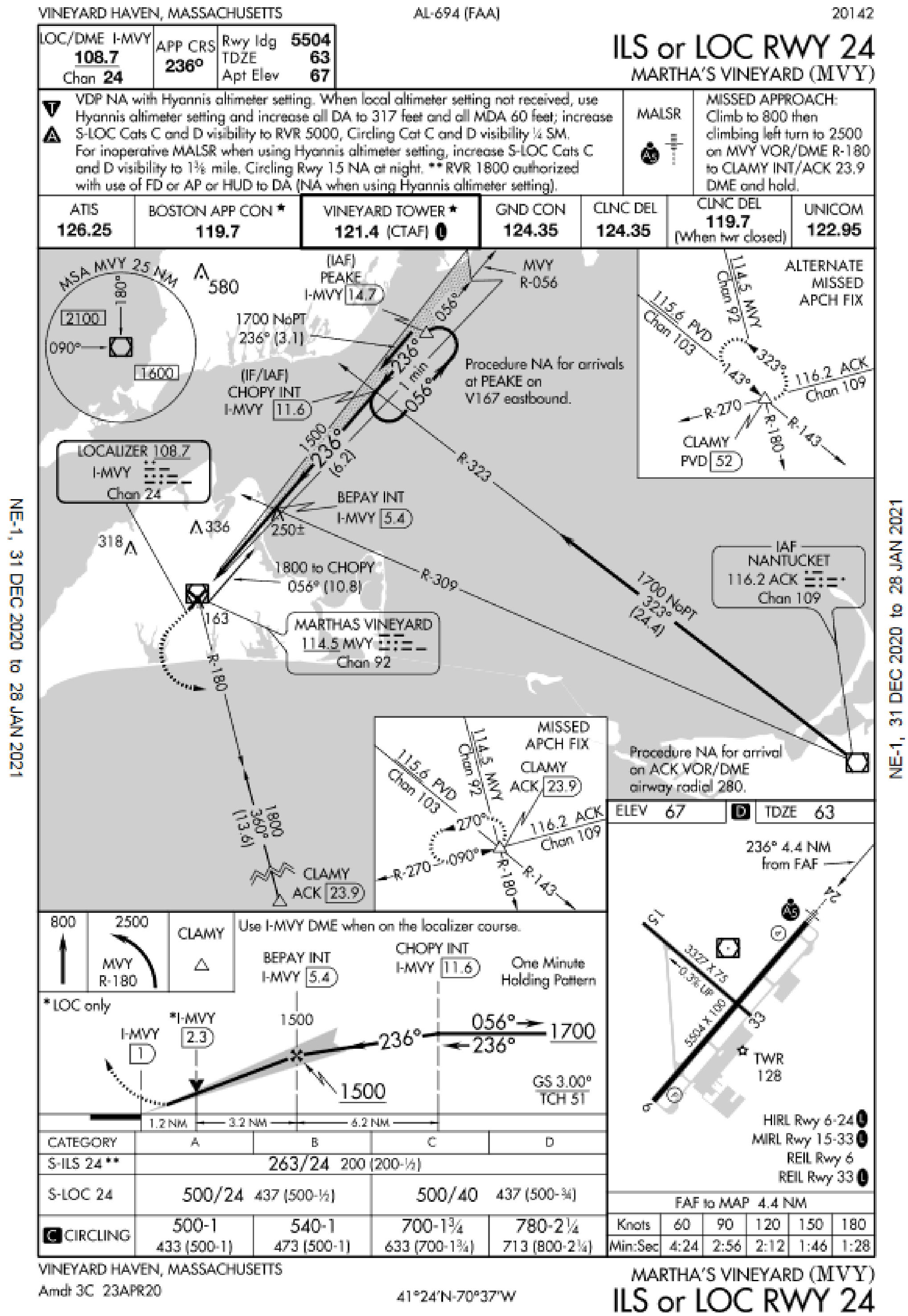
CATEGORY	A	B	C	D
S-ILS 1L	2460-¾ 284 (300-¾)			NA
S-LOC 1L	2720-¾ 544 (600-¾)		2720-1⅜ 544 (600-1⅜)	NA
CIRCLING	3020-1¼ 839 (900-1¼)	3040-1¼ 859 (900-1¼)	3100-2¾ 919 (1000-2¾)	NA

ELEV 2181 D TDZE 2176



REIL Rwys 1R, 8R, 19L and 19R
MIRL Rwy 1R-19L
HIRL Rwys 1L-19R, 8L-26R and 8R-26L

SW-4, 31 DEC 2020 to 28 JAN 2021



VINEYARD HAVEN, MASSACHUSETTS
AL-694 (FAA)
20142
LOC/DME I-MVY 108.7 Chan 24
APP CRS 236°
Rwy ldg 5504
TDZE 63
Apt Elev 67
ILS or LOC RWY 24
MARTHA'S VINEYARD (MVY)
VDP NA with Hyannis altimeter setting. When local altimeter setting not received, use Hyannis altimeter setting and increase all DA to 317 feet and all MDA 60 feet; increase S-LOC Cats C and D visibility to RVR 5000, Circling Cat C and D visibility ¼ SM. For inoperative MALSR when using Hyannis altimeter setting, increase S-LOC Cats C and D visibility to 1⅜ mile. Circling Rwy 15 NA at night. ** RVR 1800 authorized with use of FD or AP or HUD to DA (NA when using Hyannis altimeter setting).
MALSR
MISSED APPROACH: Climb to 800 then climbing left turn to 2500 on MVY VOR/DME R-180 to CLAMY INT/ACK 23.9 DME and hold.
ATIS 126.25
BOSTON APP CON ★ 119.7
VINEYARD TOWER ★ 121.4 (CTAF)
GND CON 124.35
CLNC DEL 124.35
CLNC DEL 119.7 (When twr closed)
UNICOM 122.95
MSA MVY 25 NM
180°
2100
090°
1600
580
(IAF) PEAKE I-MVY 14.7
MVY R-056
1700 NoPT 236° (3.1)
056°
236°
1 min
Procedure NA for arrivals at PEAKE on V167 eastbound.
(IF/IAF) CHOPY INT I-MVY 11.6
1500 236° (6.2)
LOCALIZER 108.7 I-MVY Chan 24
R-323
BEPAY INT I-MVY 5.4
336
318
250±
1800 to CHOPY 056° (10.8)
R-309
163
MARTHAS VINEYARD 114.5 MVY Chan 92
1700 NoPT 323° (24.4)
IAF NANTUCKET 116.2 ACK Chan 109
R-180
1800 360° (13.6)
CLAMY ACK 23.9
ALTERNATE MISSED APCH FIX
114.5 MVY Chan 92
115.6 PVD Chan 103
116.2 ACK Chan 109
323°
143°
R-270
R-143
R-180
CLAMY PVD 52
MISSED APCH FIX
CLAMY ACK 23.9
270°
090°
Procedure NA for arrival on ACK VOR/DME airway radial 280.
ELEV 67
TDZE 63
236° 4.4 NM from FAF
3327 X 75
0.3% UP
5504 X 100
TWR 128
HIRL Rwy 6-24
MIRL Rwy 15-33
REIL Rwy 6
REIL Rwy 33
800
2500
MVY R-180
CLAMY
Use I-MVY DME when on the localizer course.
BEPAY INT I-MVY 5.4
CHOPY INT I-MVY 11.6
One Minute Holding Pattern
*LOC only
I-MVY 1
*I-MVY 2.3
1500
056° 1700
236°
1500
GS 3.00° TCH 51
1.2 NM
3.2 NM
6.2 NM
CATEGORY A B C D
S-ILS 24 ** 263/24 200 (200-½)
S-LOC 24 500/24 437 (500-½) 500/40 437 (500-¾)
CIRCLING 500-1 433 (500-1) 540-1 473 (500-1) 700-1¾ 633 (700-1¾) 780-2¼ 713 (800-2¼)
FAF to MAP 4.4 NM
Knots 60 90 120 150 180
Min:Sec 4:24 2:56 2:12 1:46 1:28
VINEYARD HAVEN, MASSACHUSETTS
Amdt 3C 23APR20
41°24'N-70°37'W
MARTHA'S VINEYARD (MVY)
ILS or LOC RWY 24
NE-1, 31 DEC 2020 to 28 JAN 2021

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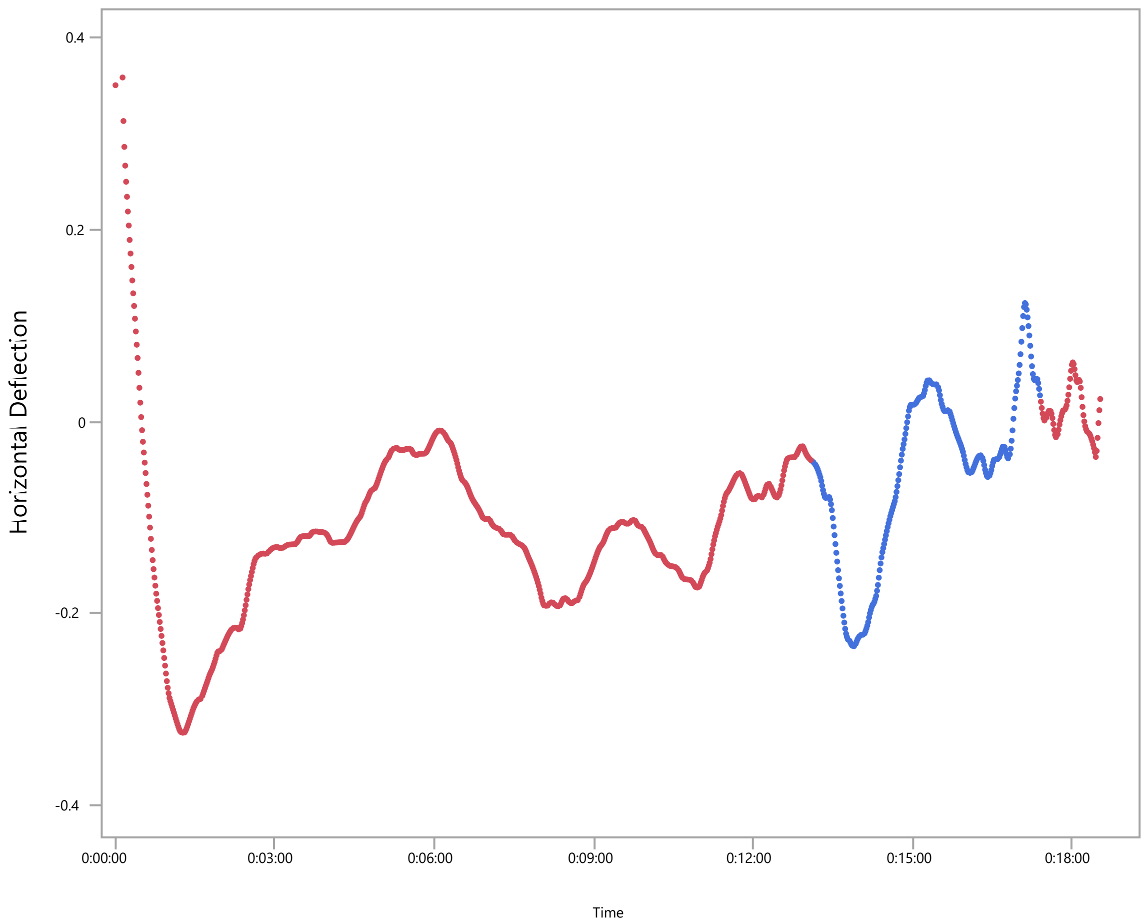
APPENDIX C. TIME SERIES PLOTS

The line in blue denotes the data derived from the final approach portion of the flight, i.e., the portion that was used for all further analysis.



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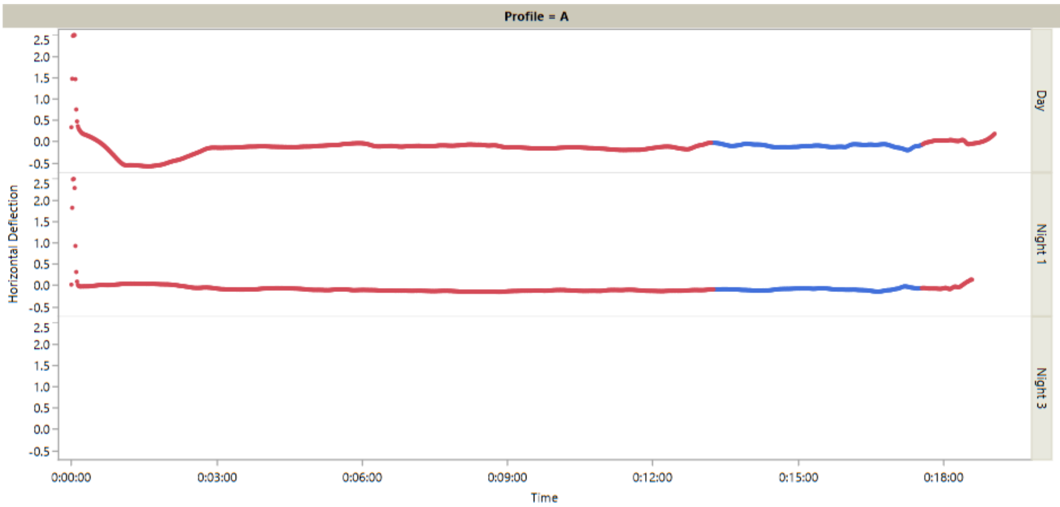

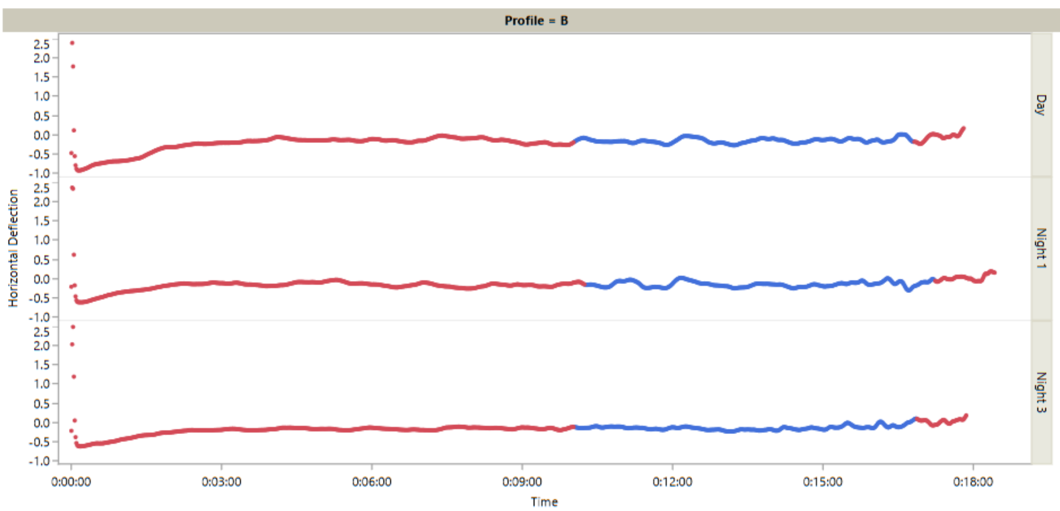

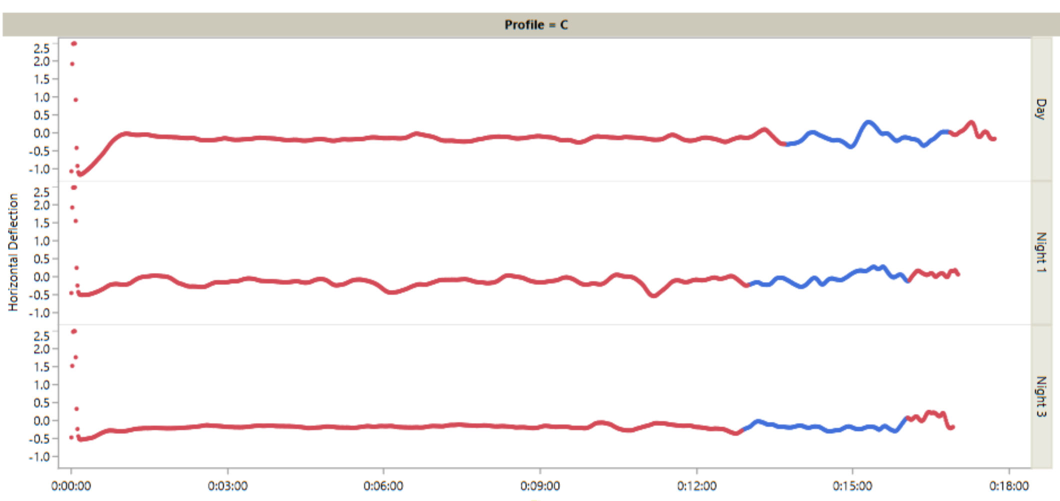

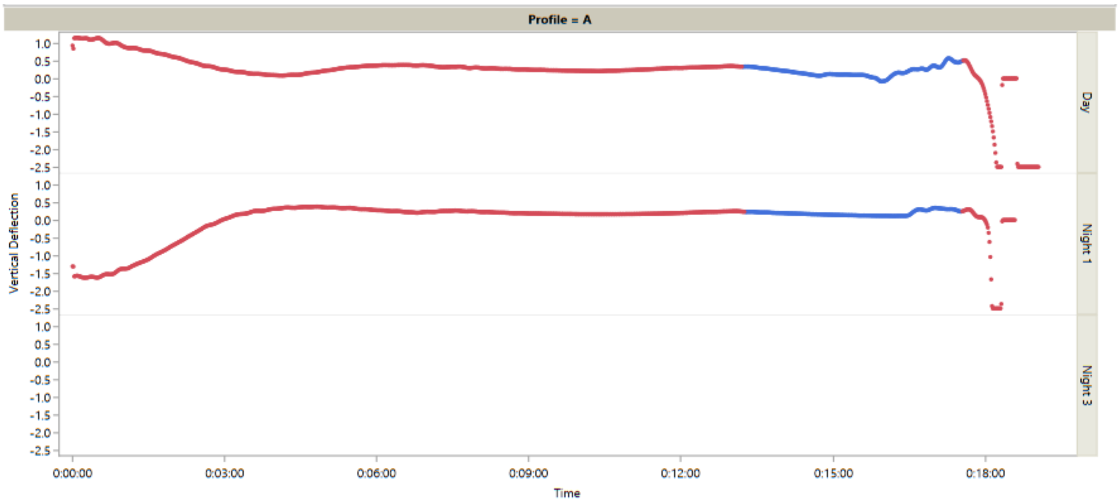
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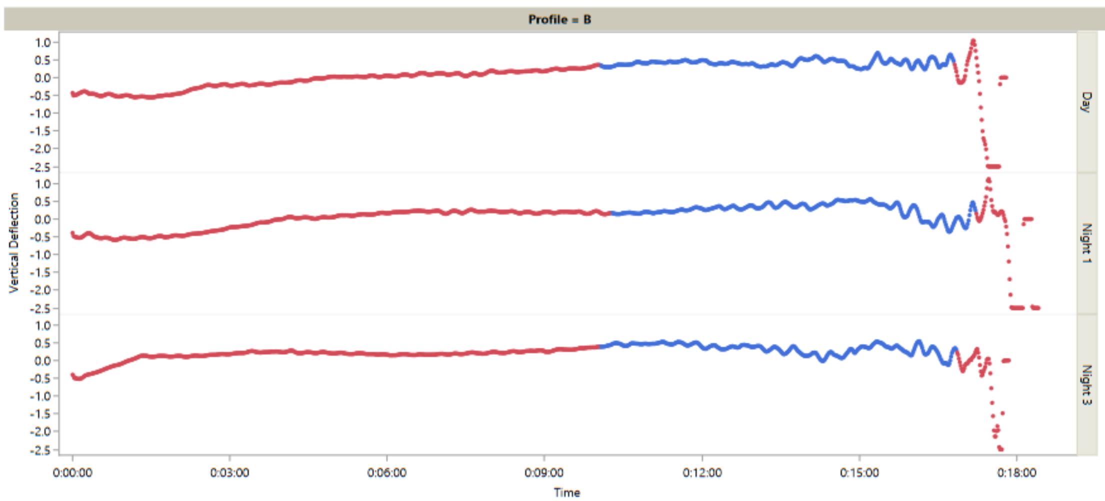
Night 1
Night 3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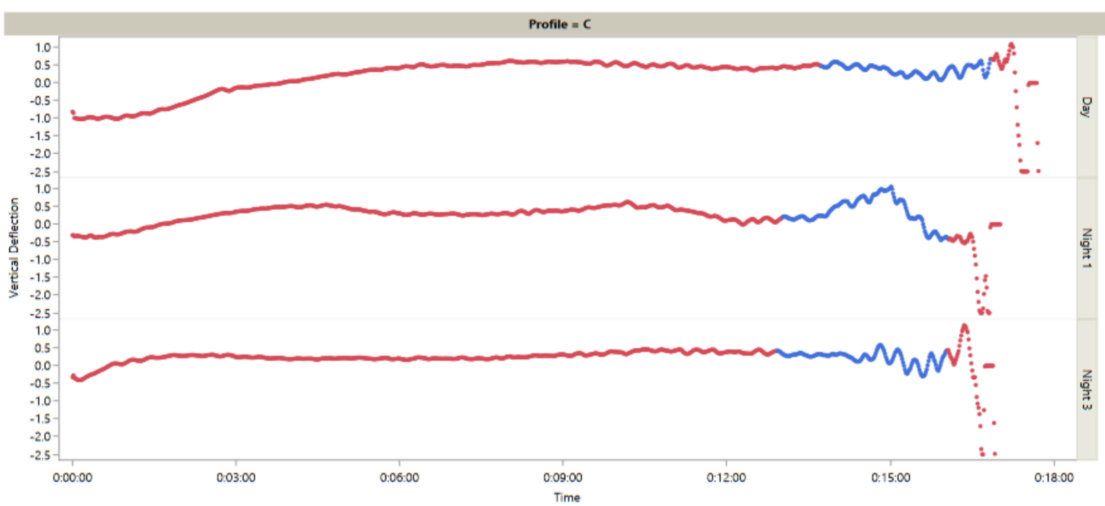
Day
Night 1
Night 3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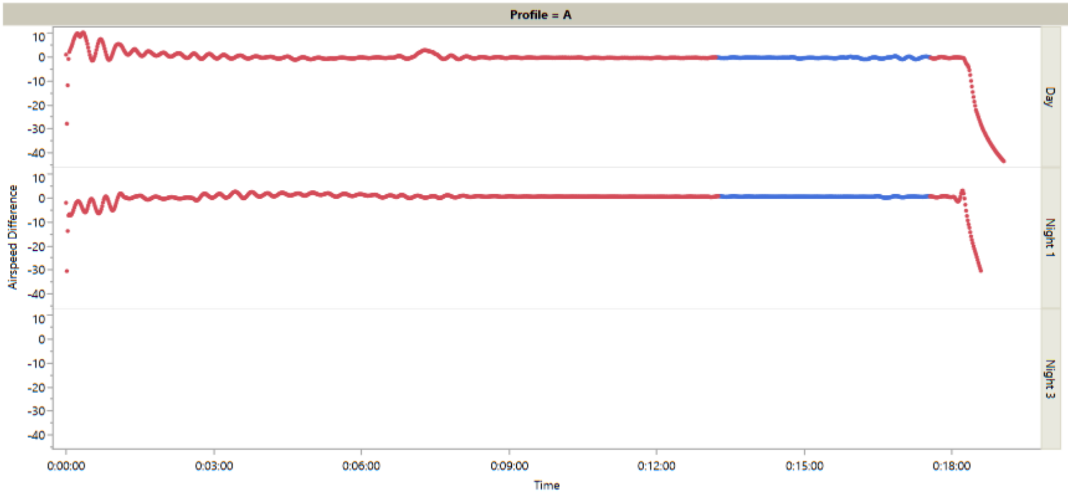
Time
Day
Night 1
Night 3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Airspeed Difference
Time
Day
Night 1
Night 3
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0
-10
-20
-30
-40
0:00:00
0:03:00
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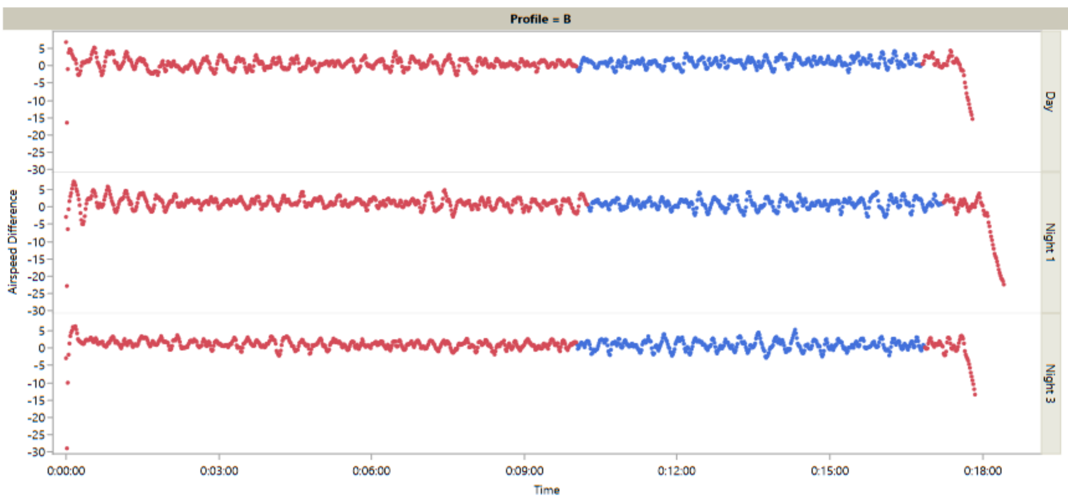
0:09:00
0:12:00
0:15:00
0:18:00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Airspeed Difference
Time
Day
Night 1
Night 3
5
0
-5
-10
-15
-20
-25
-30
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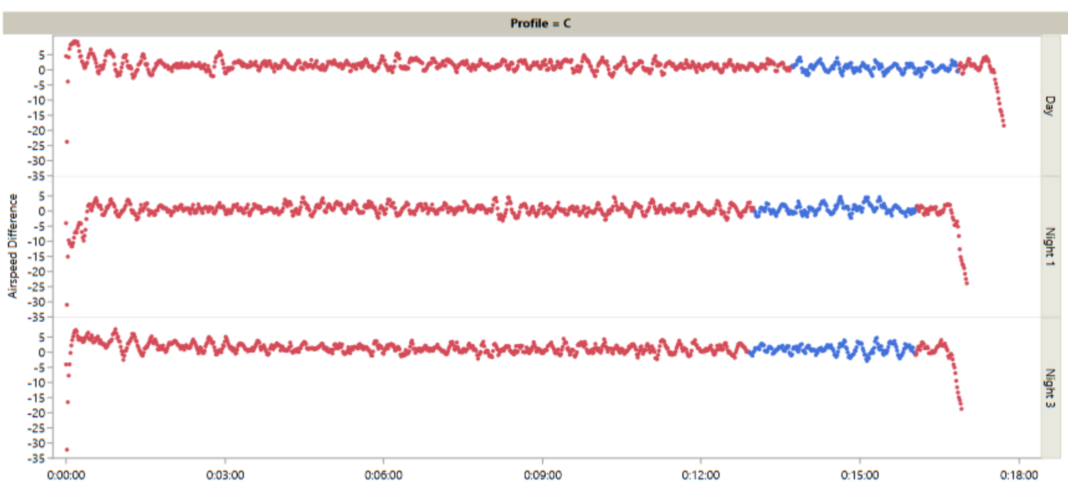
0:15:00
0:18:00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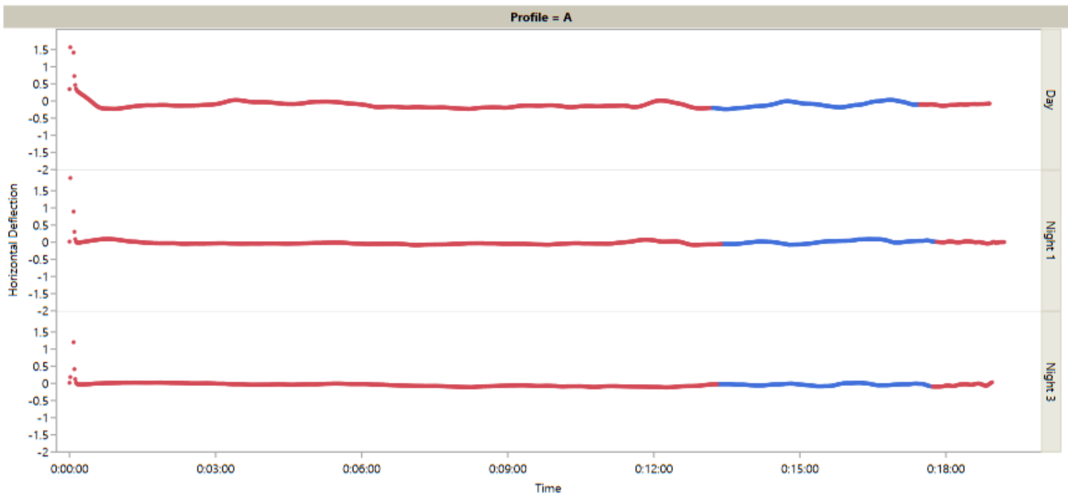
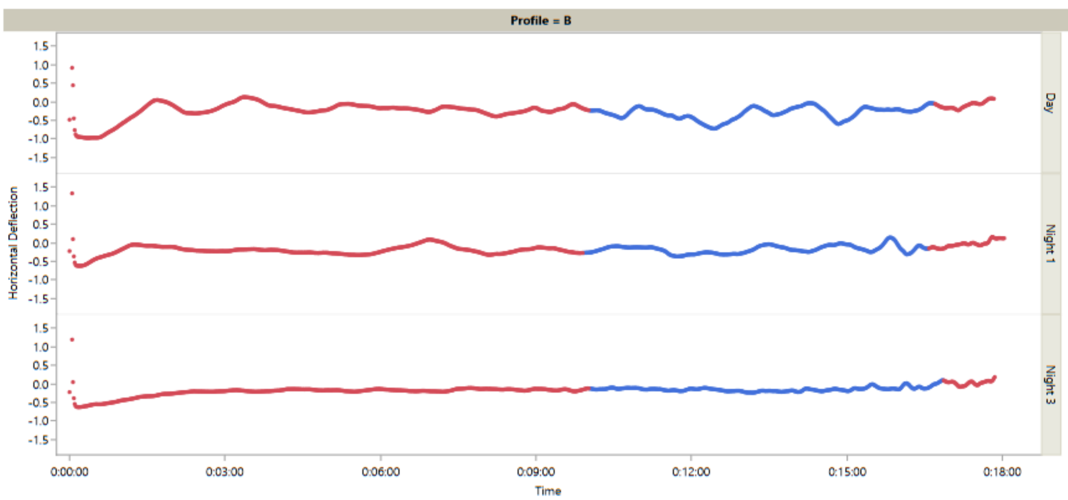
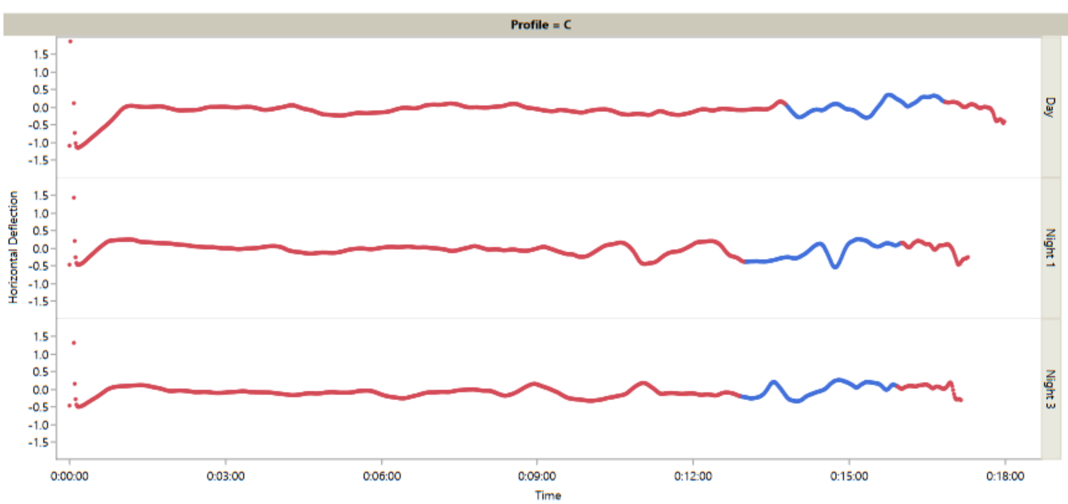
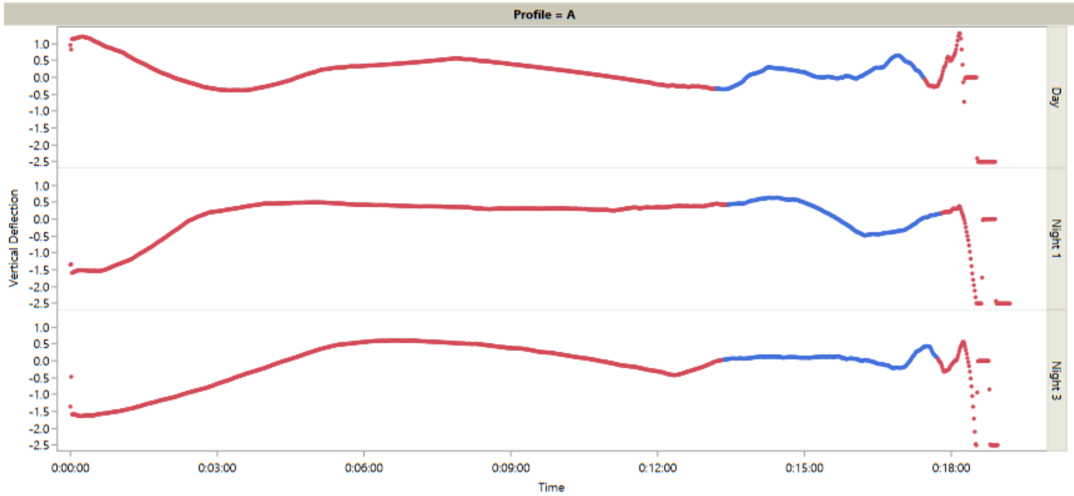
Airspeed Difference
Time
Day
Night 1
Night 3
5
0
-5
-10
-15
-20
-25
-30
-35
0:00:00
0:03:00
0:06:00
0:09:00
0:12:00
0:15:00
0:18:00

2. Participant 2





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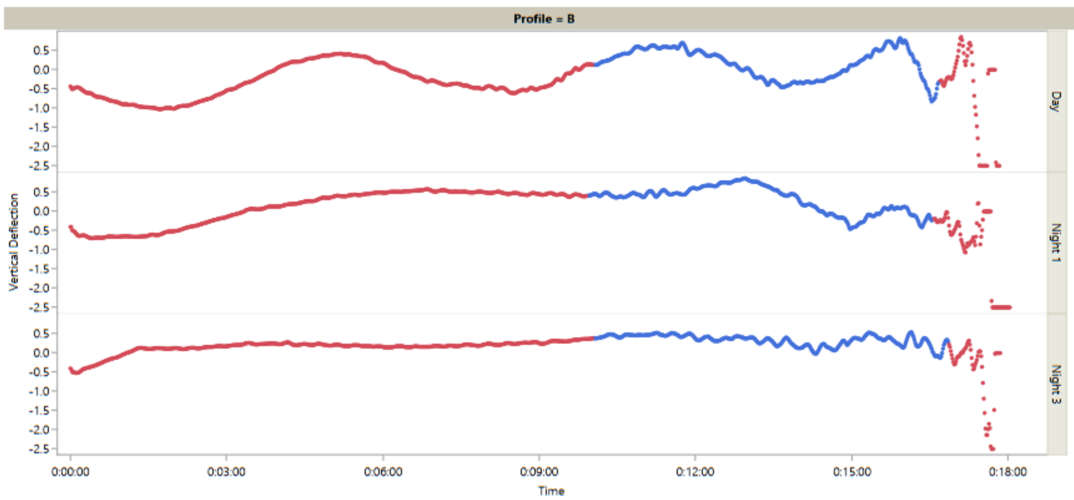
Vertical Deflection
Time
Day
Night 1
Night 3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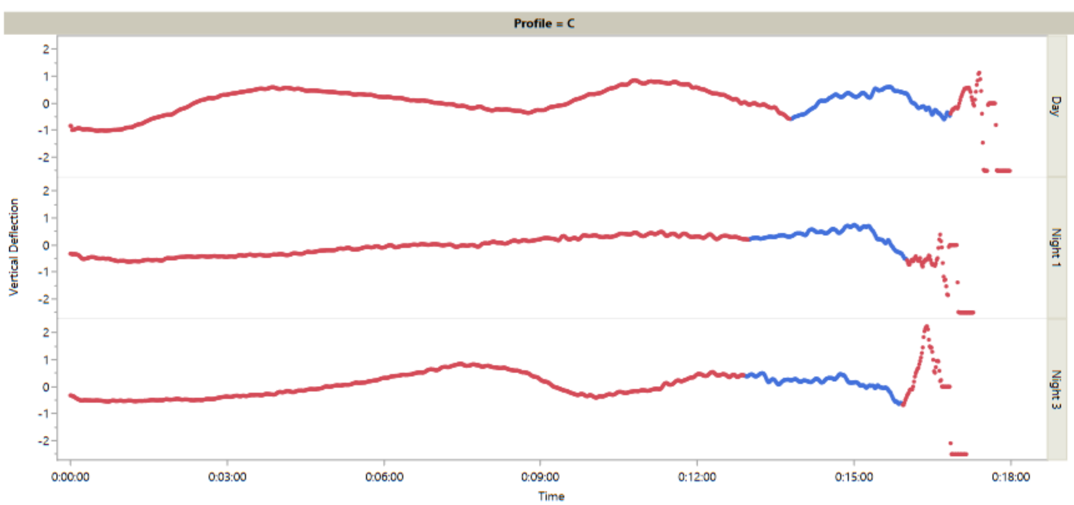
Time
Day
Night 1
Night 3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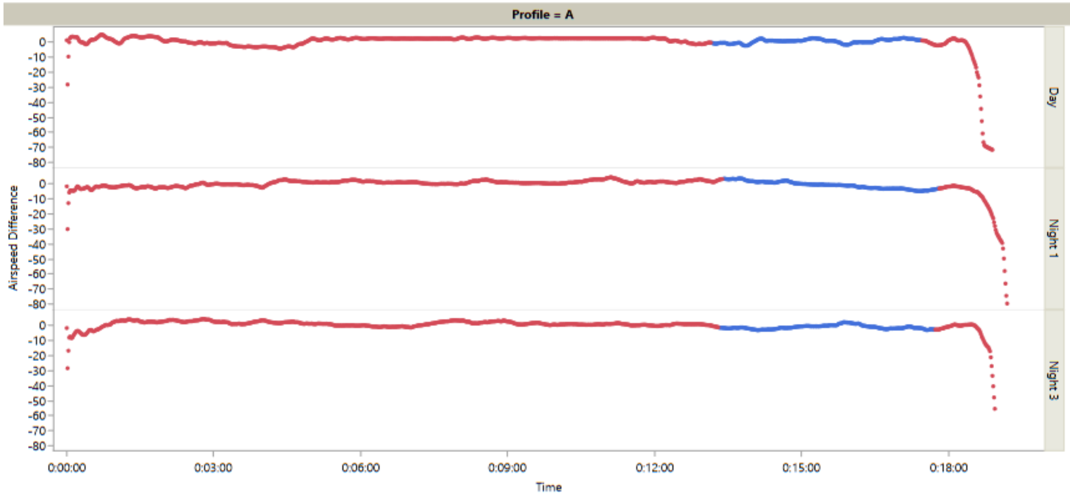
Vertical Deflection
Time
Day
Night 1
Night 3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Airspeed Difference
0
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-20
-30
-40
-50
-60
-70
-80
Day
Night 1
Night 3
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0:06:00
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0:12:00
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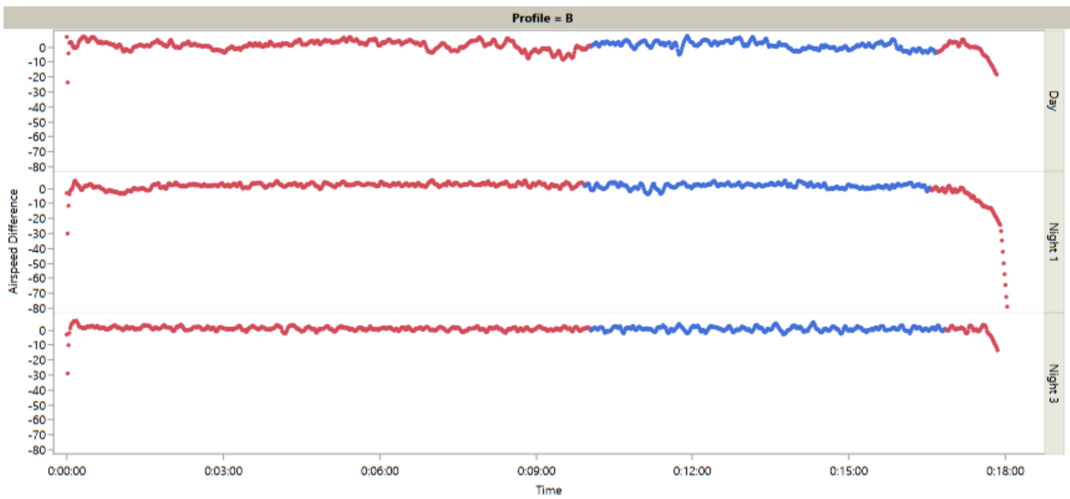
Time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Airspeed Difference
0
-10
-20
-30
-40
-50
-60
-70
-80
Day
Night 1
Night 3
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0:03:00
0:06:00
0:09:00
0:12:00
0:15:00
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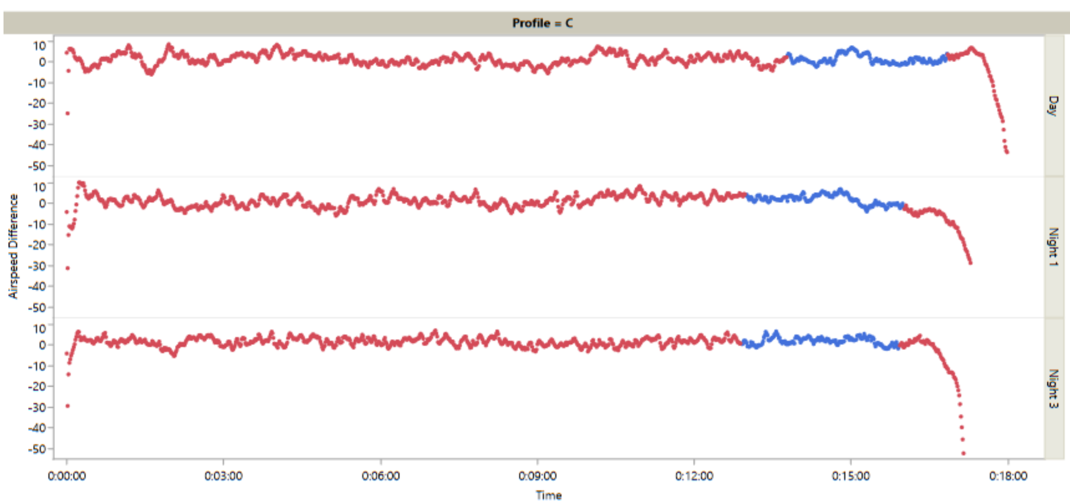
Time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Airspeed Difference
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-30
-40
-50
Day
Night 1
Night 3
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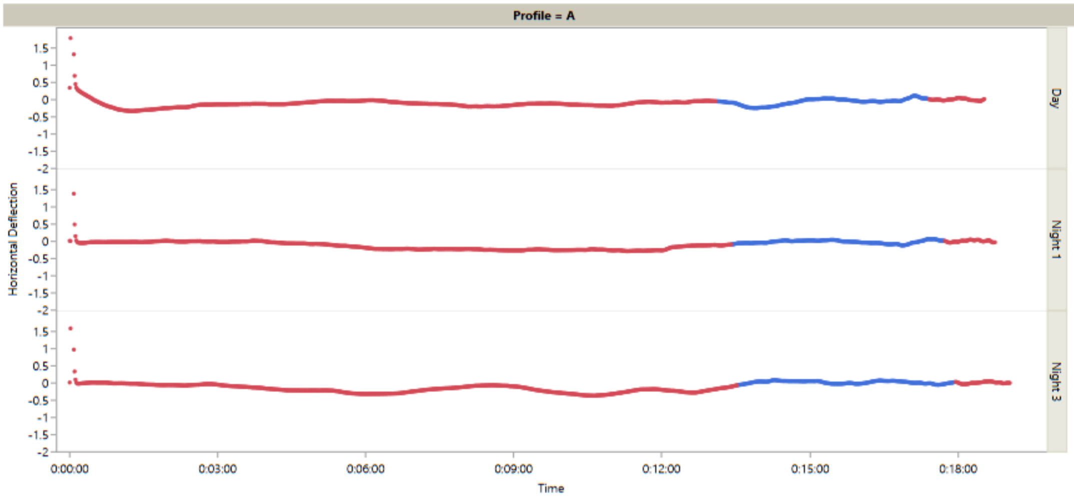
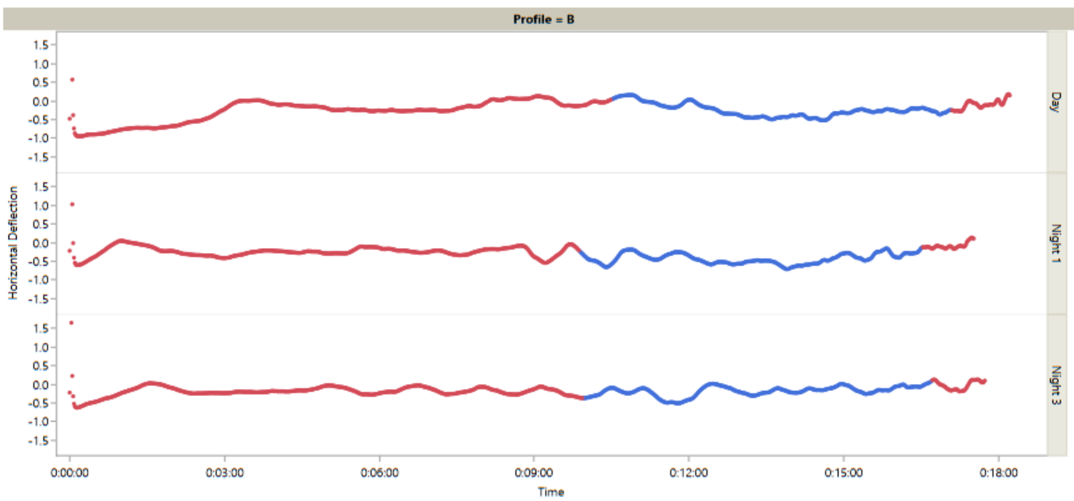
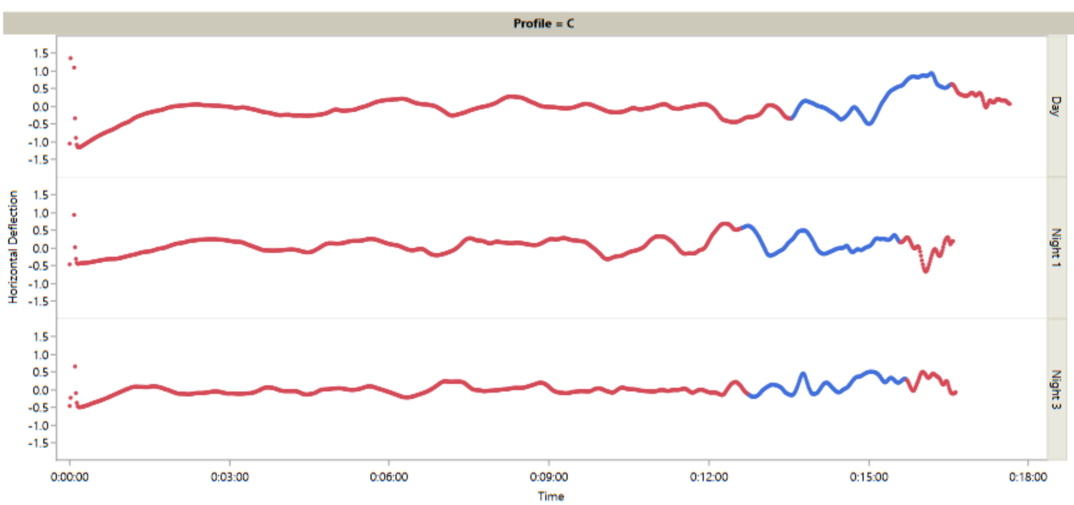
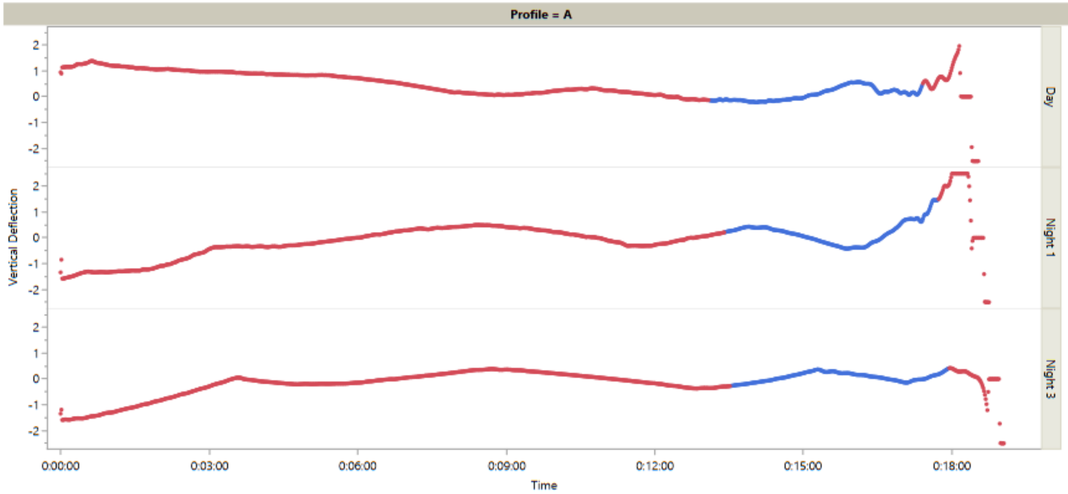
0:15:00
0:18:00
Time

3. Participant 3





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Night 3
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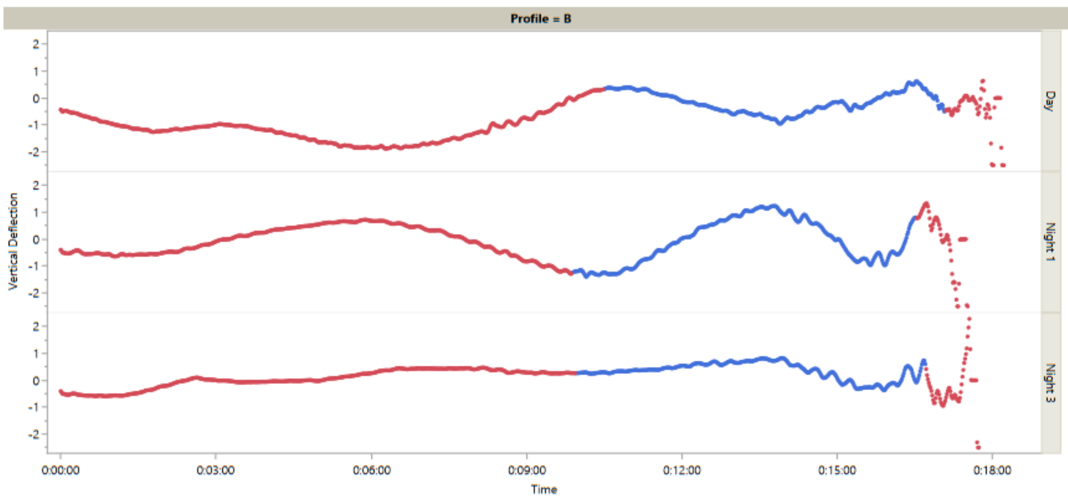
Time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Night 3
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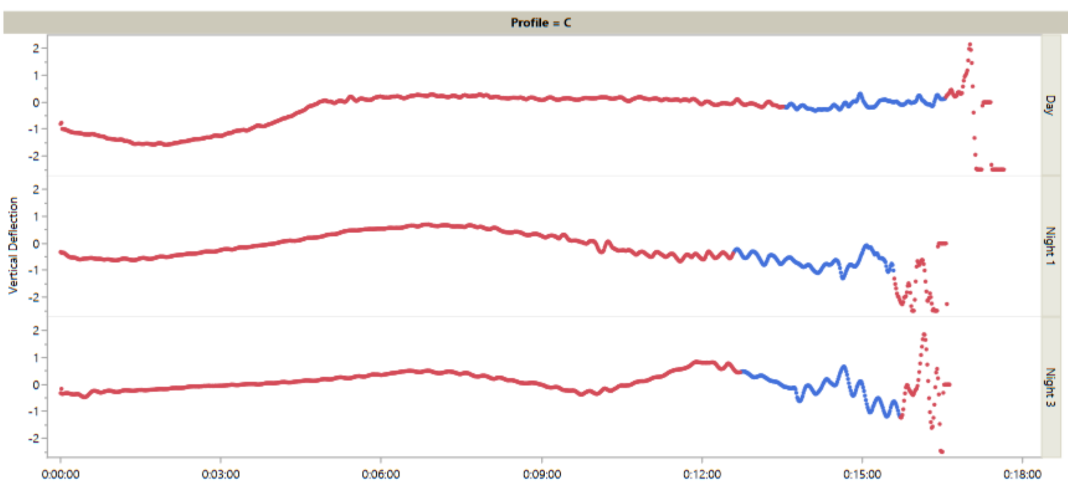
Time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Night 3
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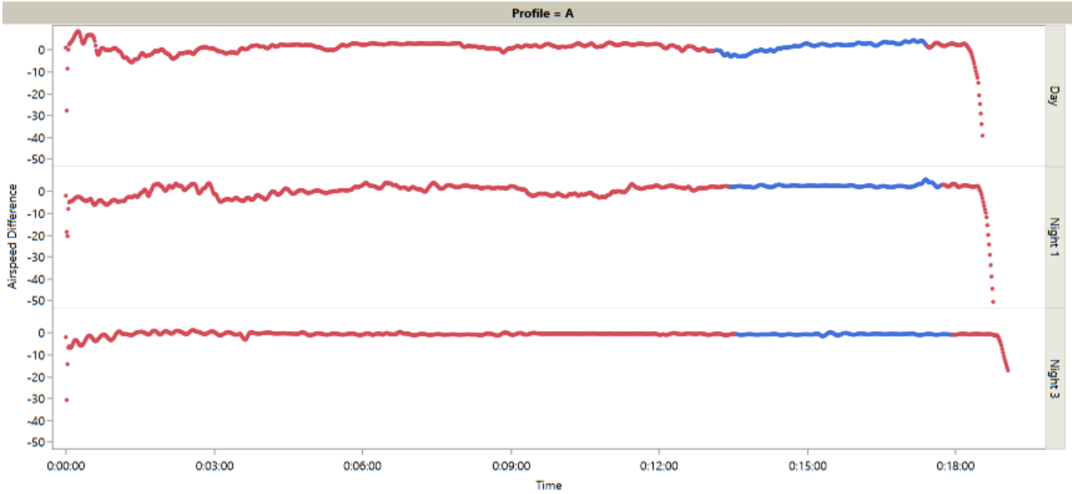
Time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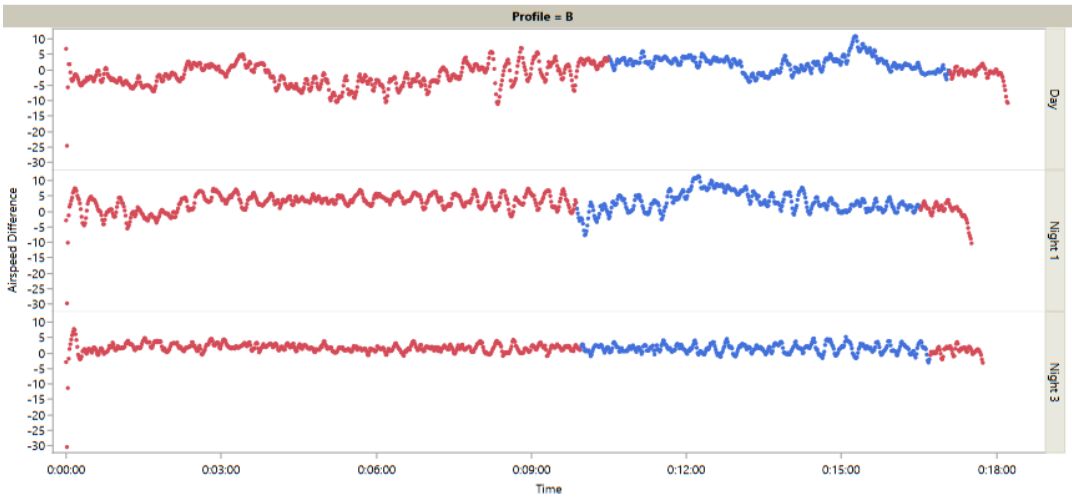
Day
Night 1
Night 3
Time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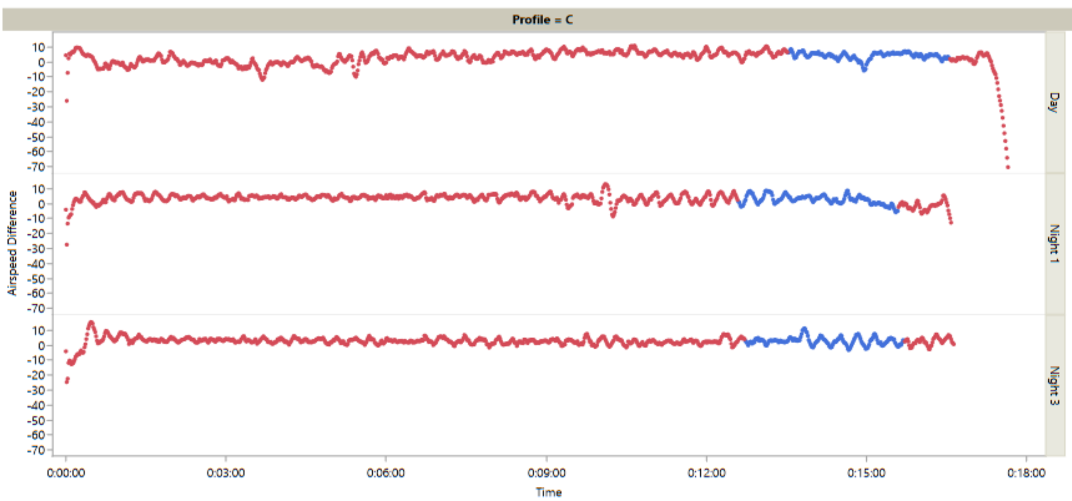
Airspeed Difference
Day
Night 1
Night 3
Time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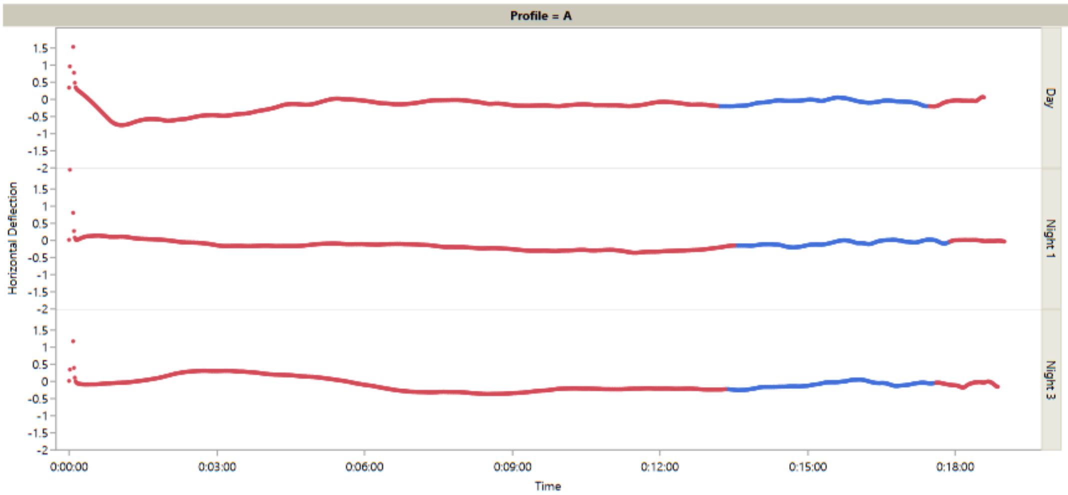
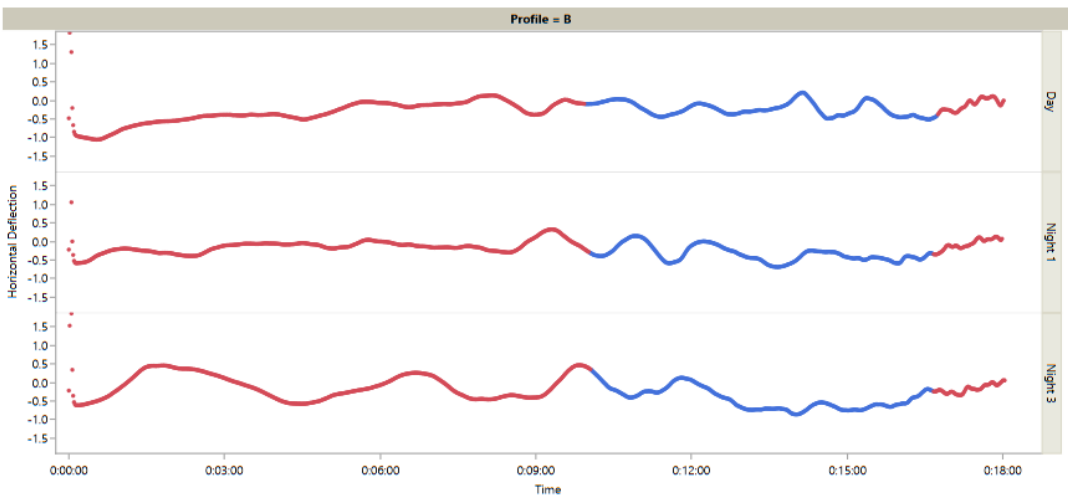
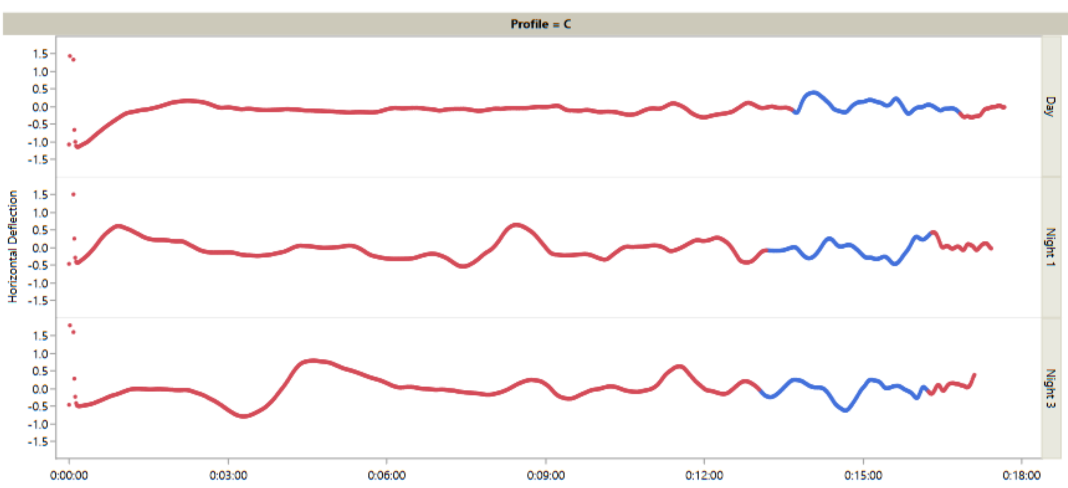
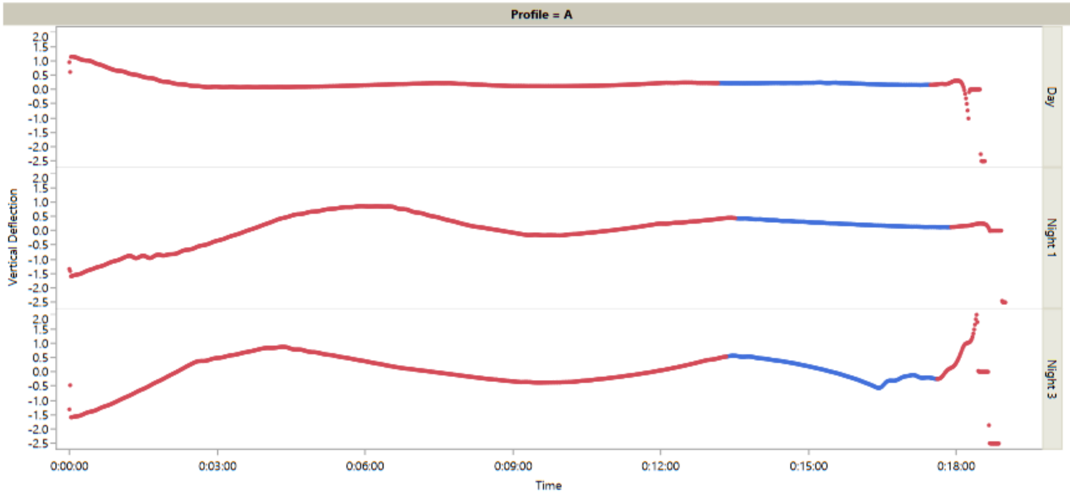
Airspeed Difference
Day
Night 1
Night 3
Time

4. Participant 5





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Night 3
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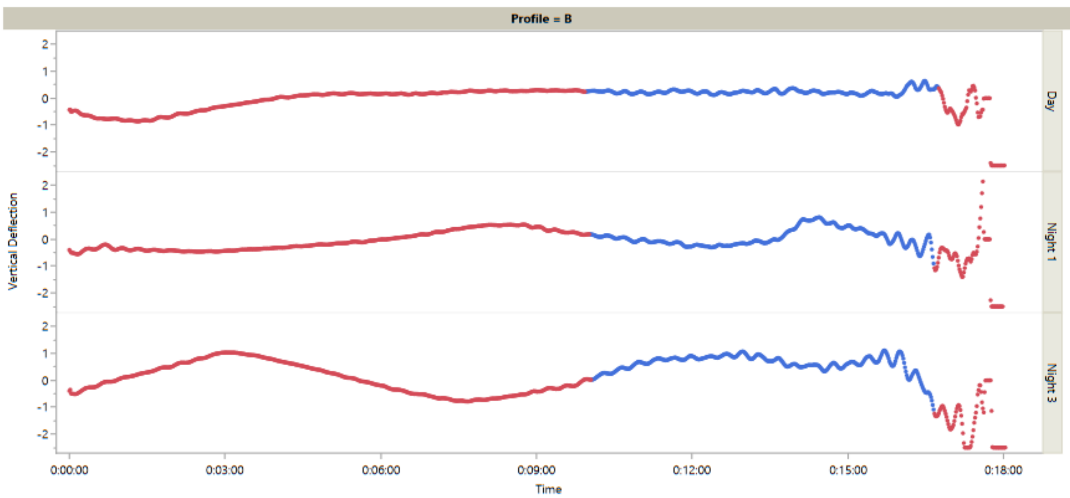
Time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Night 3
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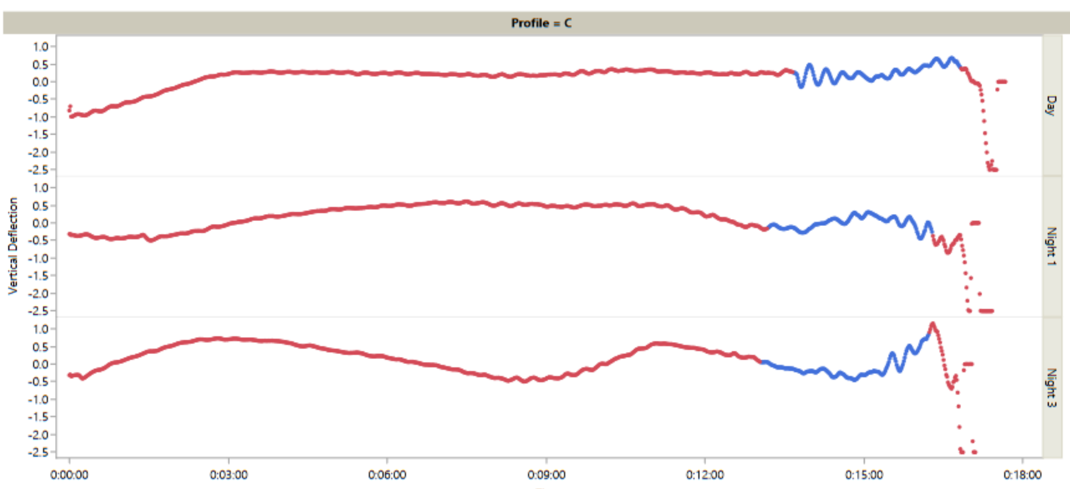
Time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Vertical Deflection
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Night 3
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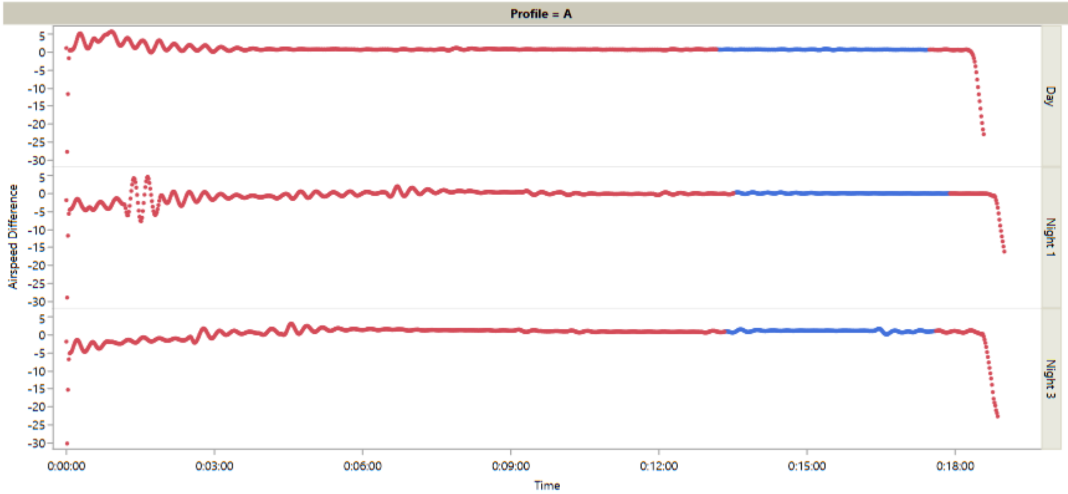
Time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Airspeed Difference
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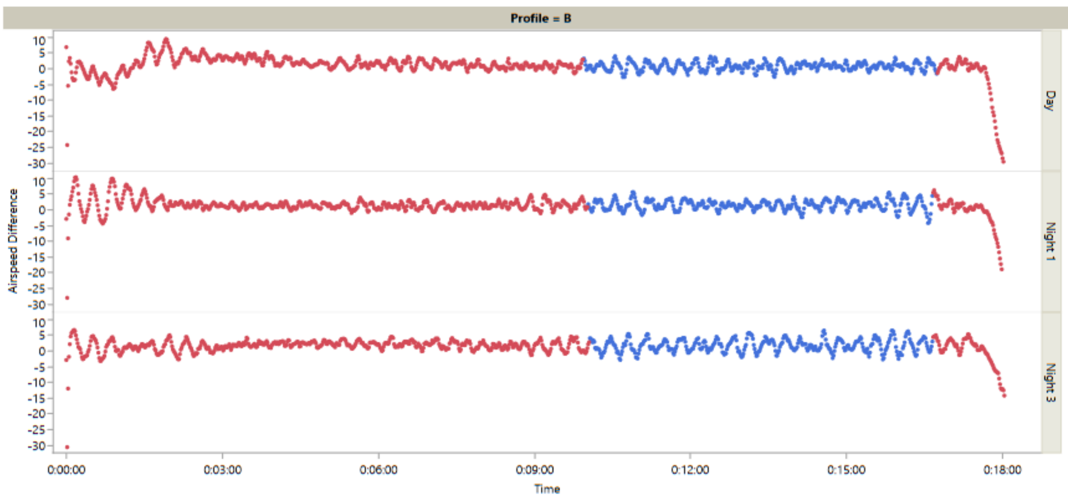
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Airspeed Difference
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Night 1
Night 3
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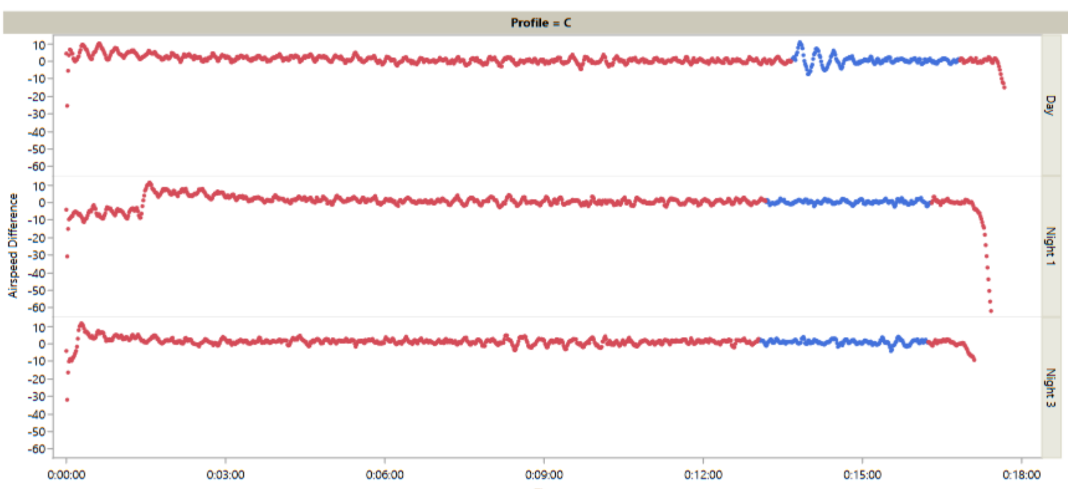
Profile = C
Airspeed Difference
Time
Day
Night 1
Night 3
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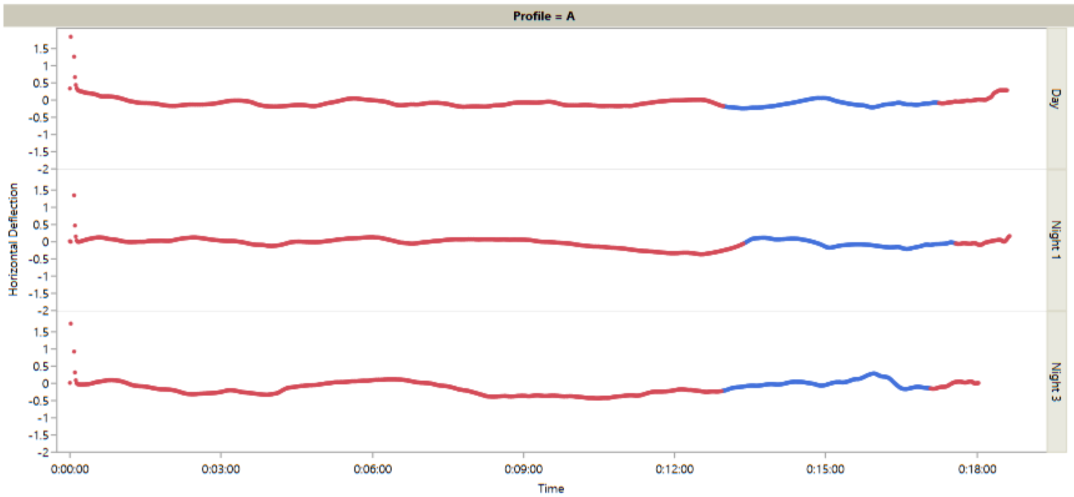
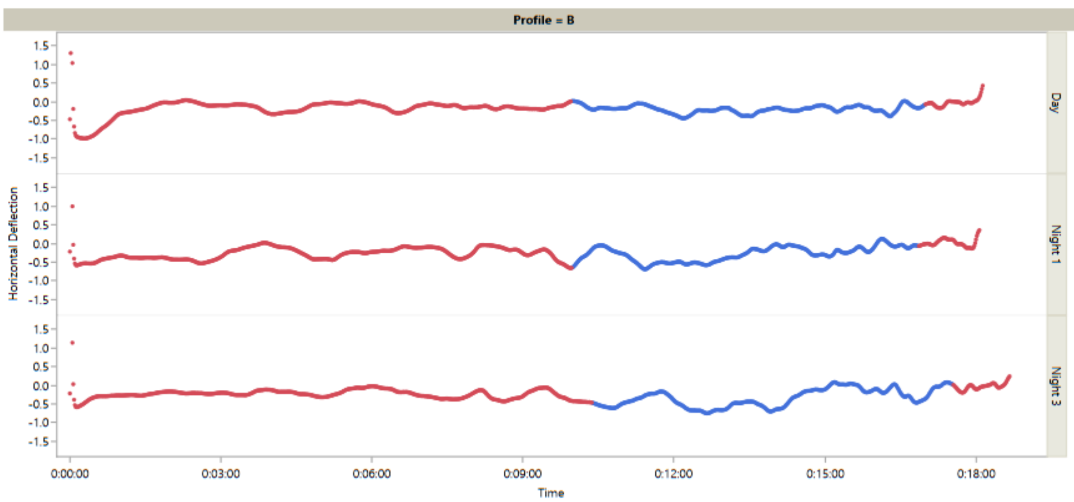
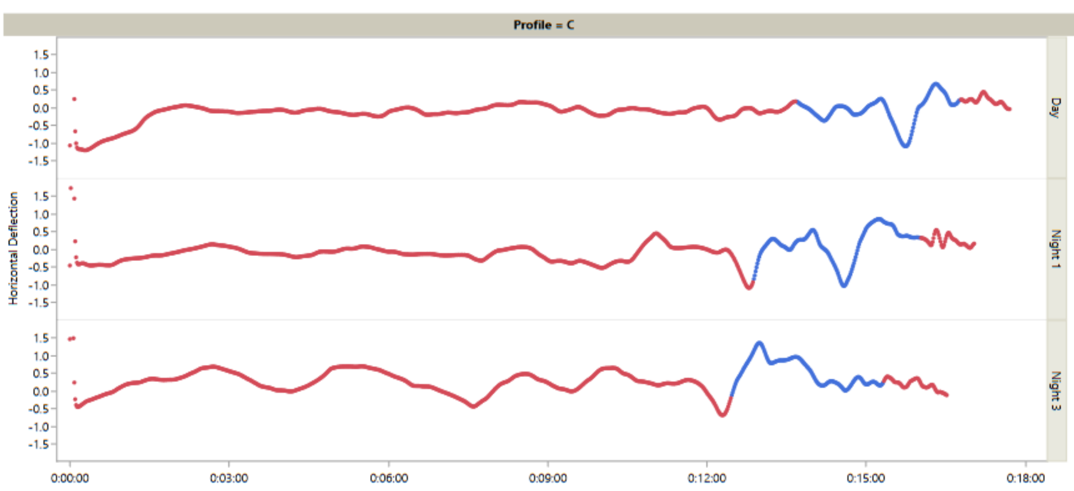
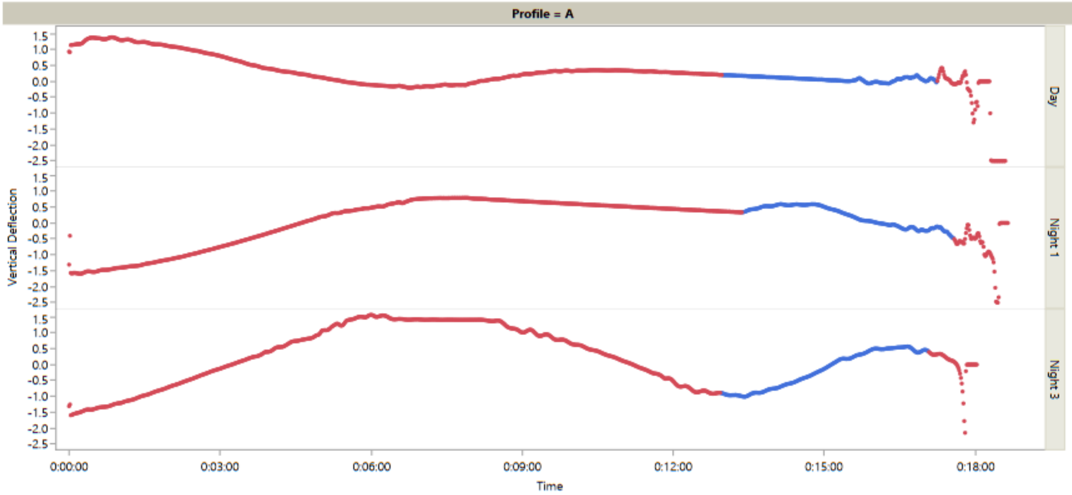
5. Participant 6








Profile = A
Vertical Deflection
Time
Day
Night 1
Night 3
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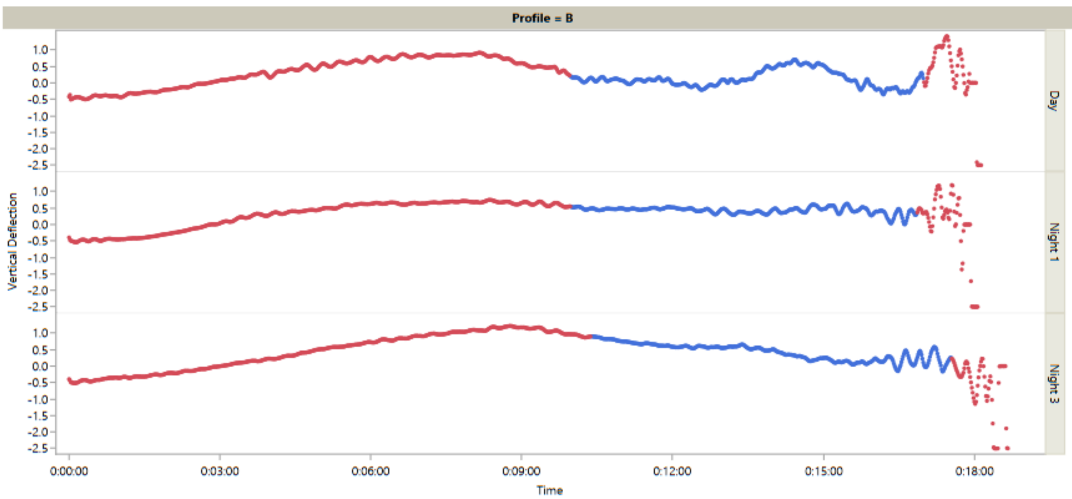
Profile = B
Vertical Deflection
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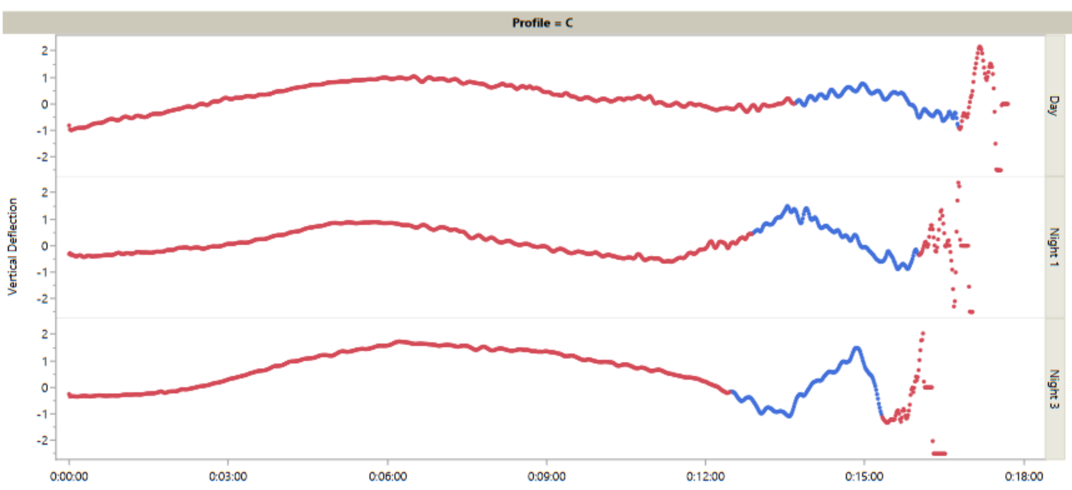
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Vertical Deflection
Time
Day
Night 1
Night 3
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0:15:00
0:18:00


Profile = A
Airspeed Difference
Day
Night 1
Night 3
0
-20
-40
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0:03:00
0:06:00
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0:15:00
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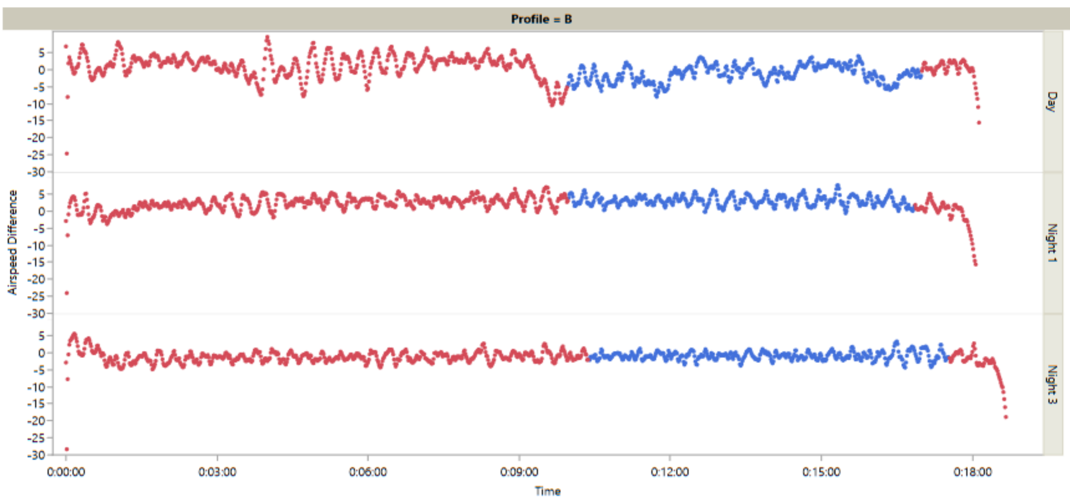
Time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Airspeed Difference
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Night 1
Night 3
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-5
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-15
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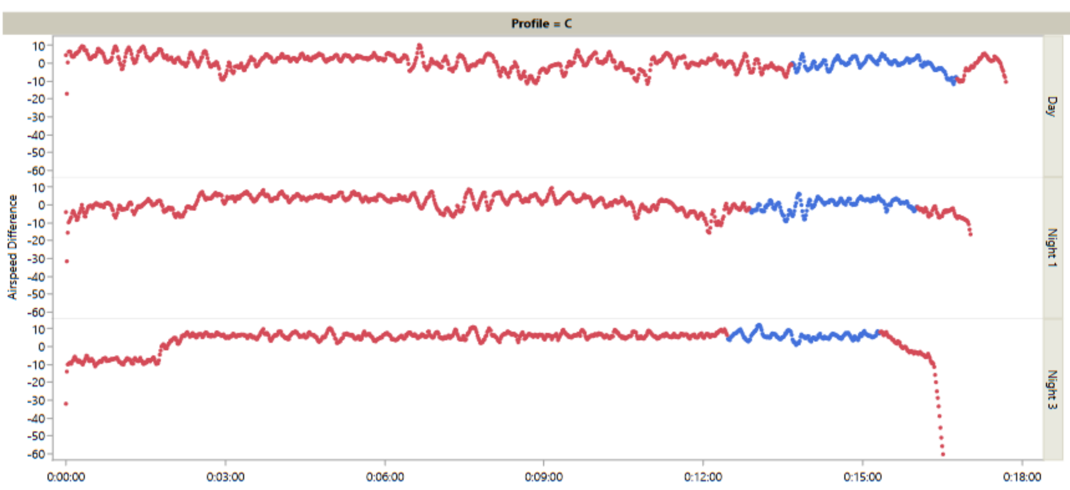
0:15:00
0:18:00
Time


Profile = C
Airspeed Difference
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Night 1
Night 3
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-50
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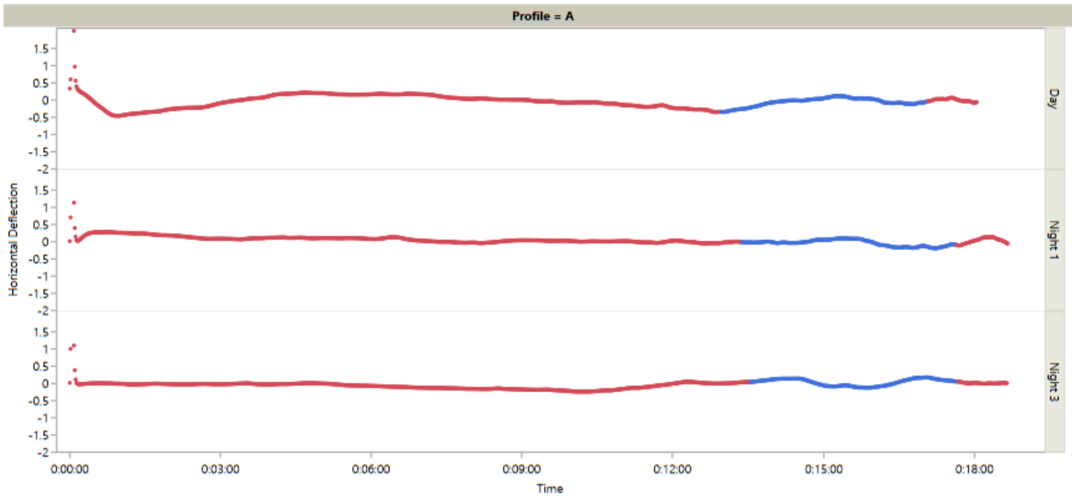
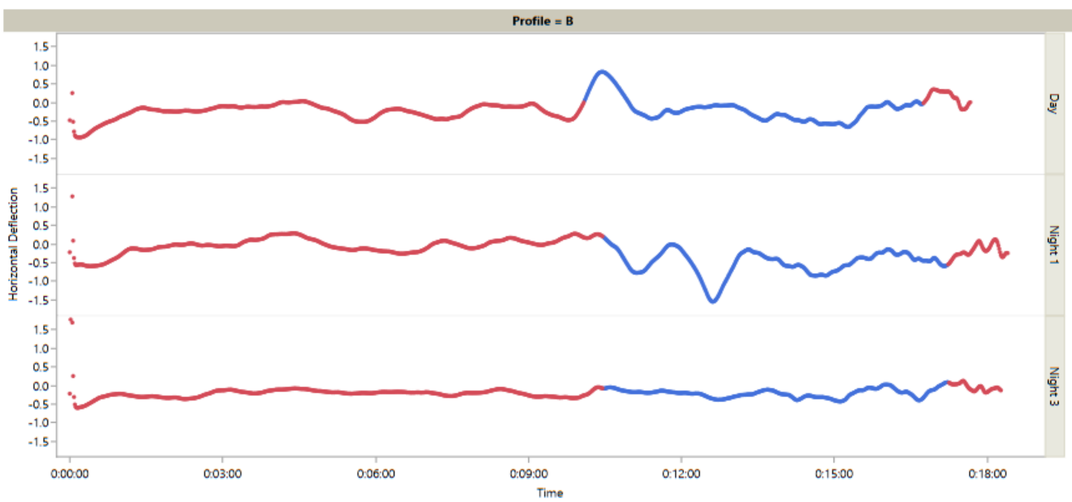
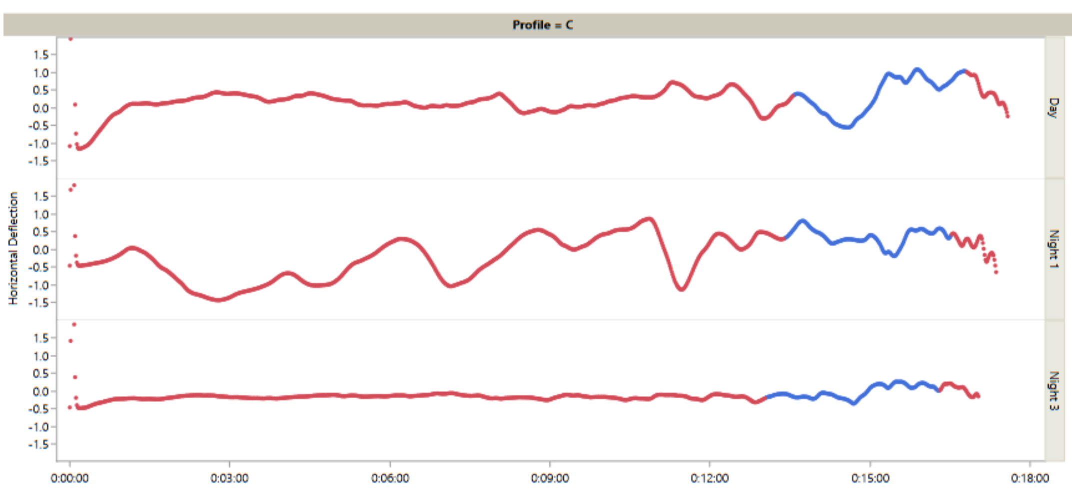
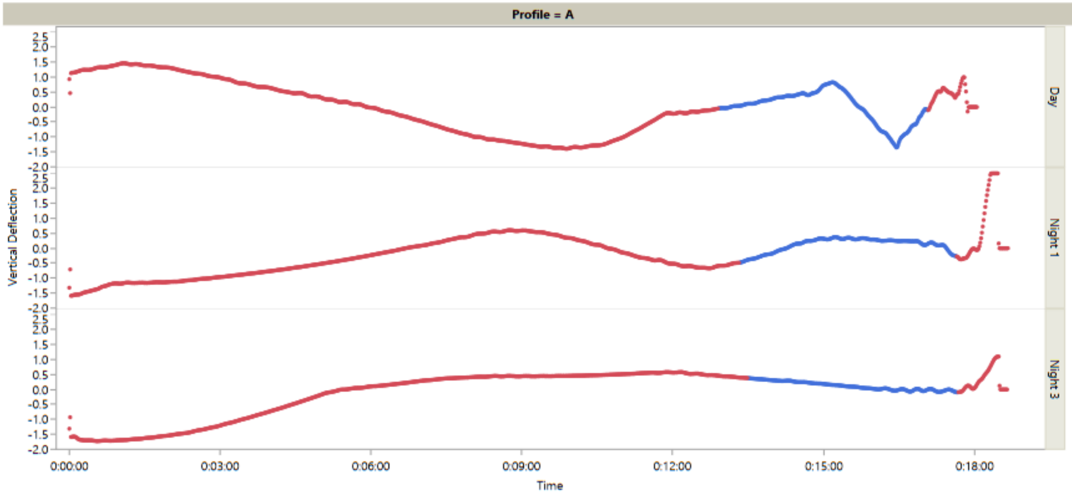
Time

6. Participant 7





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Vertical Deflection
Time
Day
Night 1
Night 3
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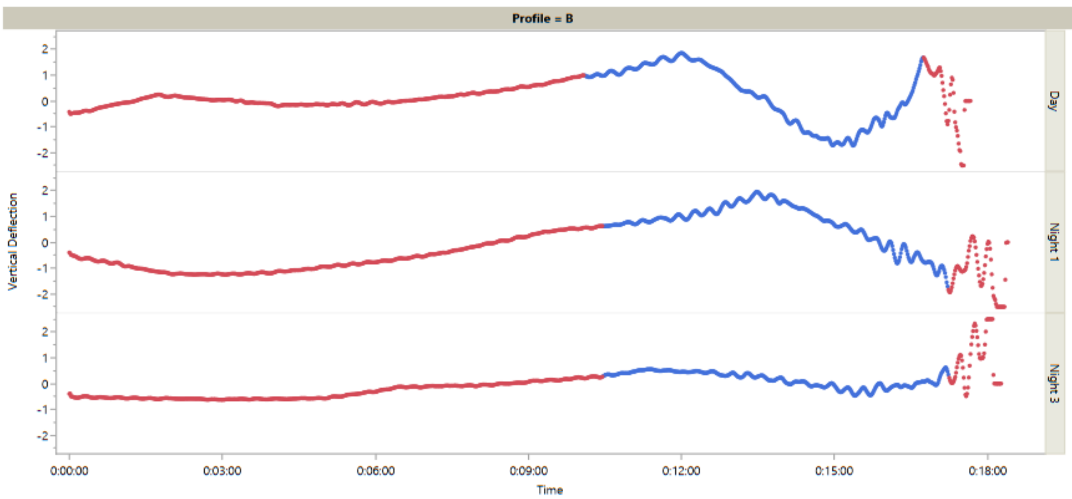
0:18:00


Profile = B
Vertical Deflection
Time
Day
Night 1
Night 3
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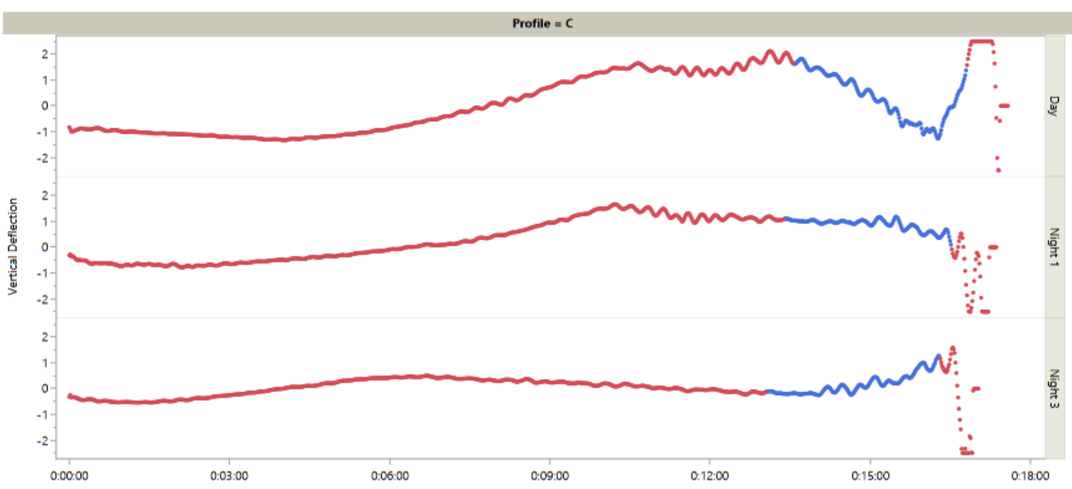
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Vertical Deflection
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Night 1
Night 3
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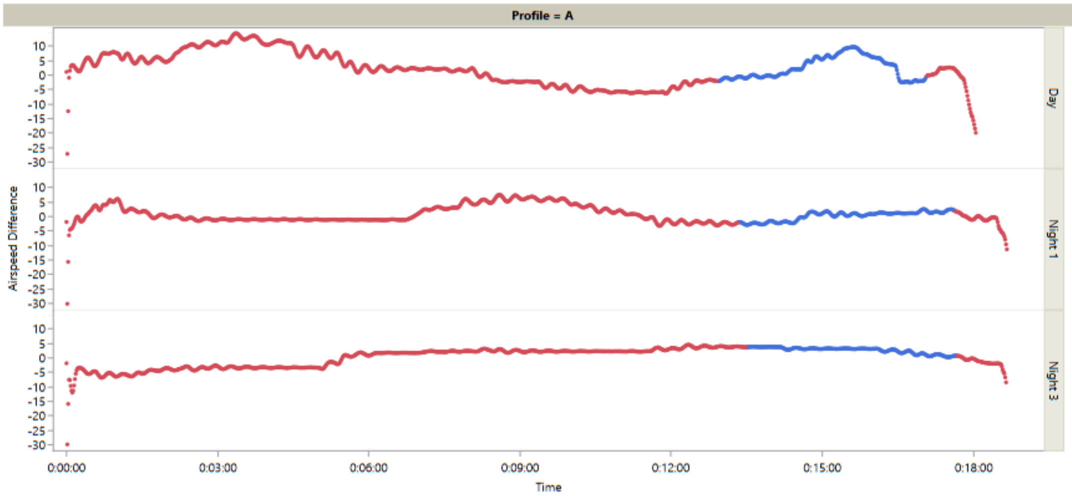
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Airspeed Difference
Day
Night 1
Night 3
Time
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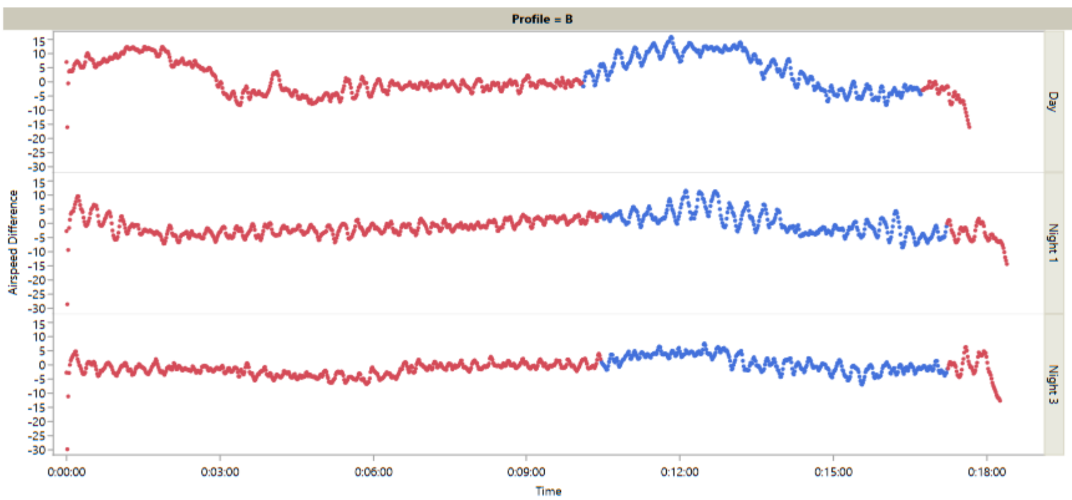
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Airspeed Difference
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Night 3
Time
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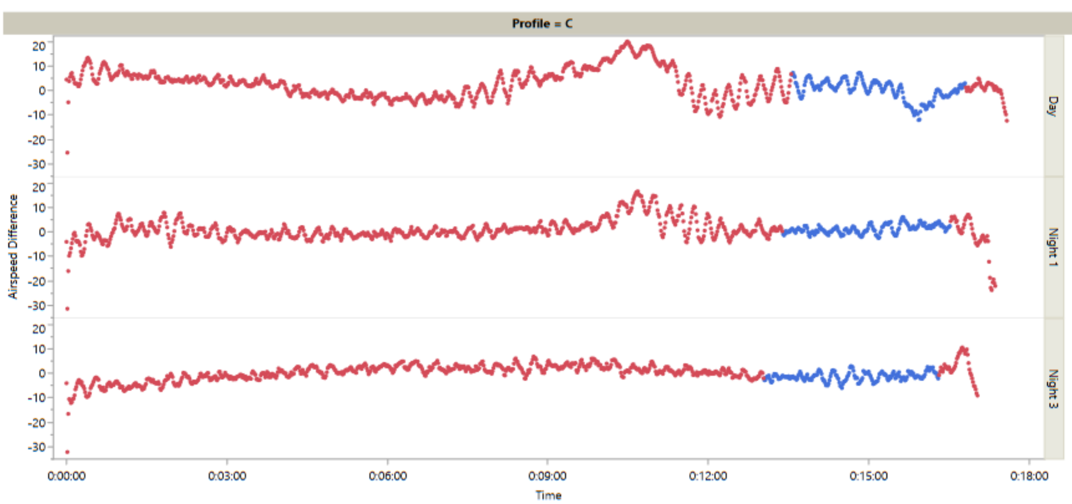
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Airspeed Difference
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Night 1
Night 3
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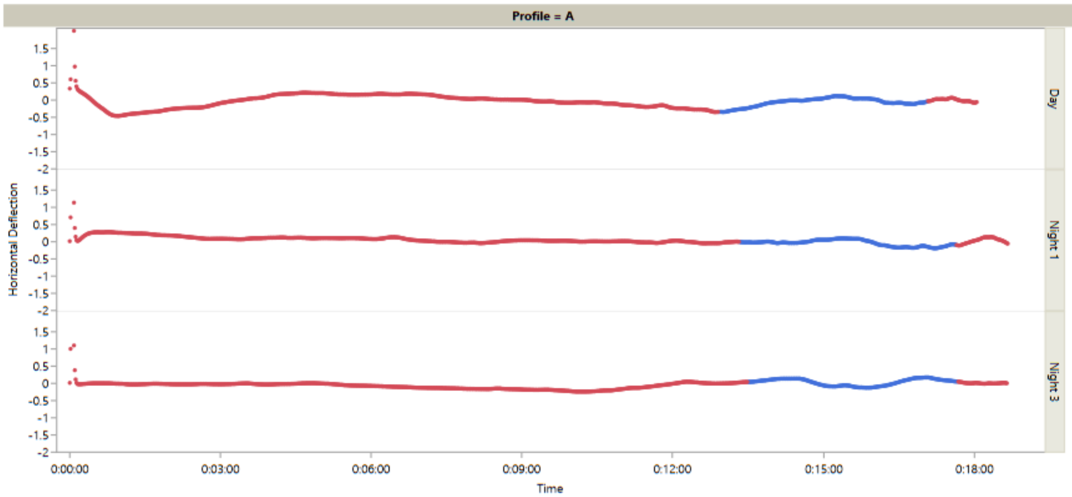
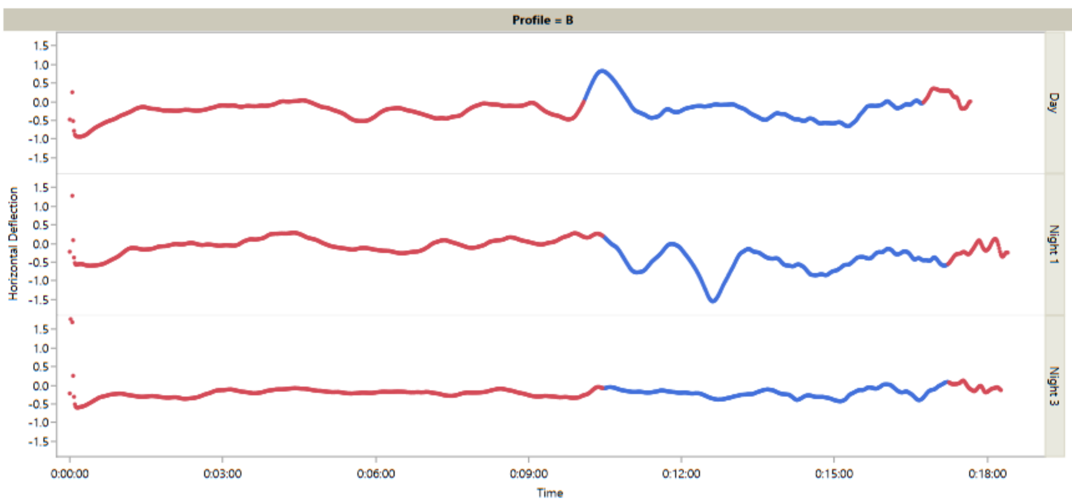
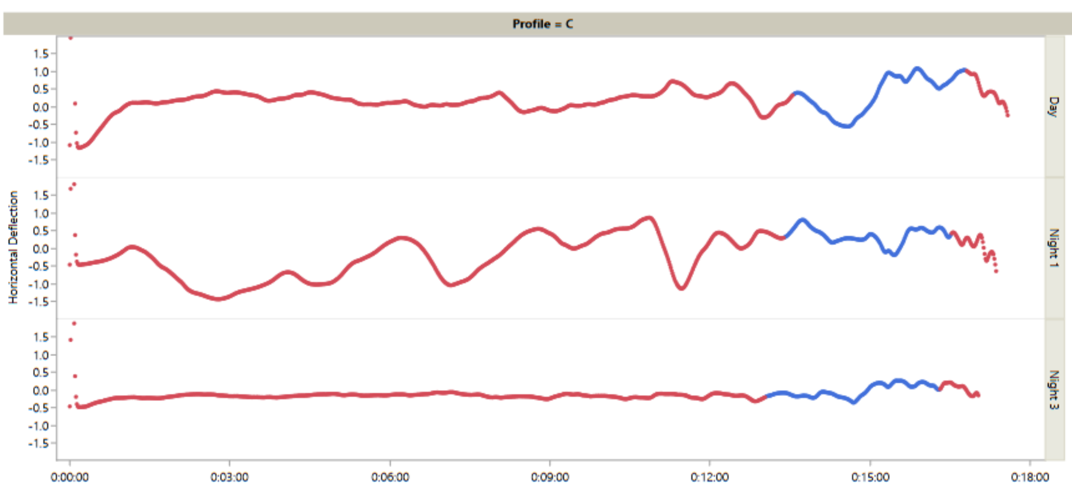
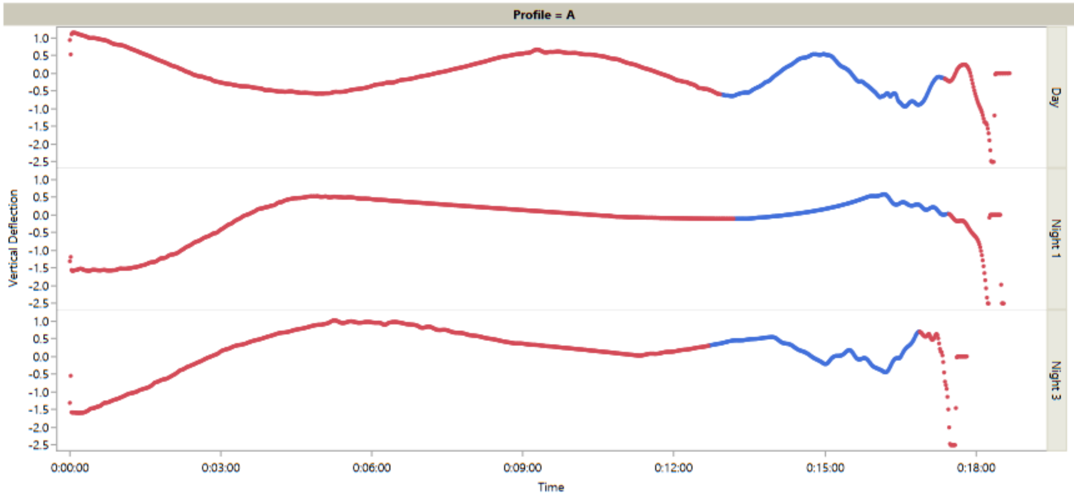
7. Participant 8





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-1.5
-2.0
-2.5
Day
Night 1
Night 3
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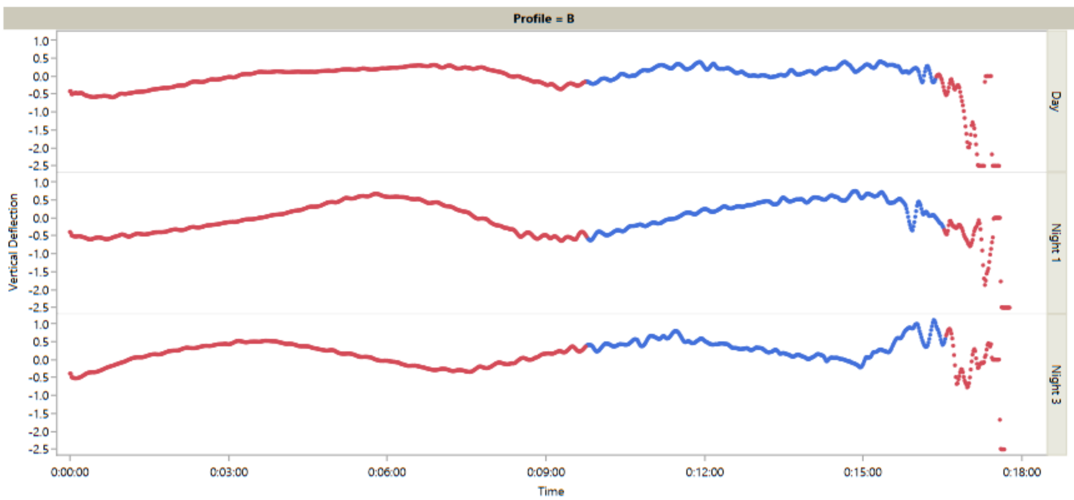
0:03:00
0:06:00
0:09:00
0:12:00
0:15:00
0:18:00
Time


Profile = B
Vertical Deflection
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-2.5
Day
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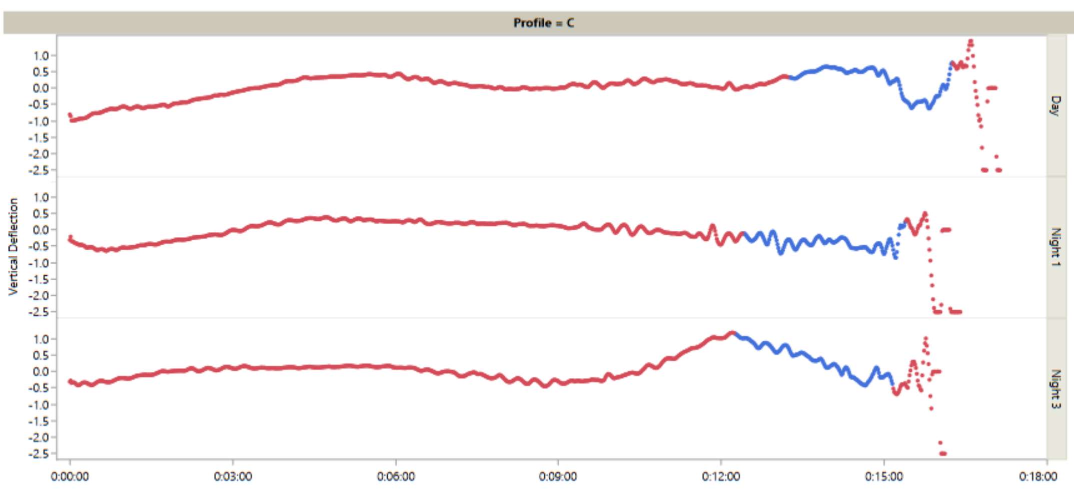
Time


Profile = C
Vertical Deflection
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-2.0
-2.5
Day
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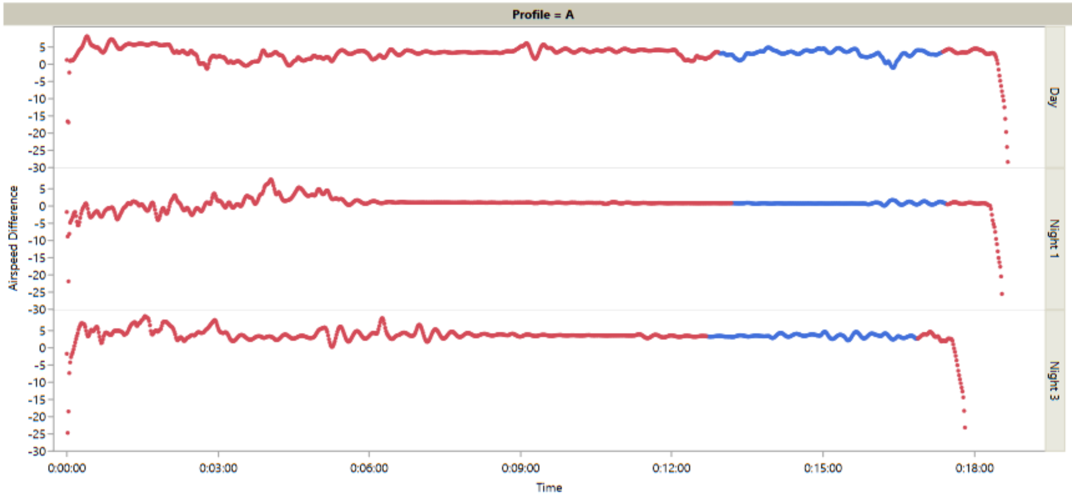
Time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Airspeed Difference
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-15
-20
-25
-30
Day
Night 1
Night 3
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0:15:00
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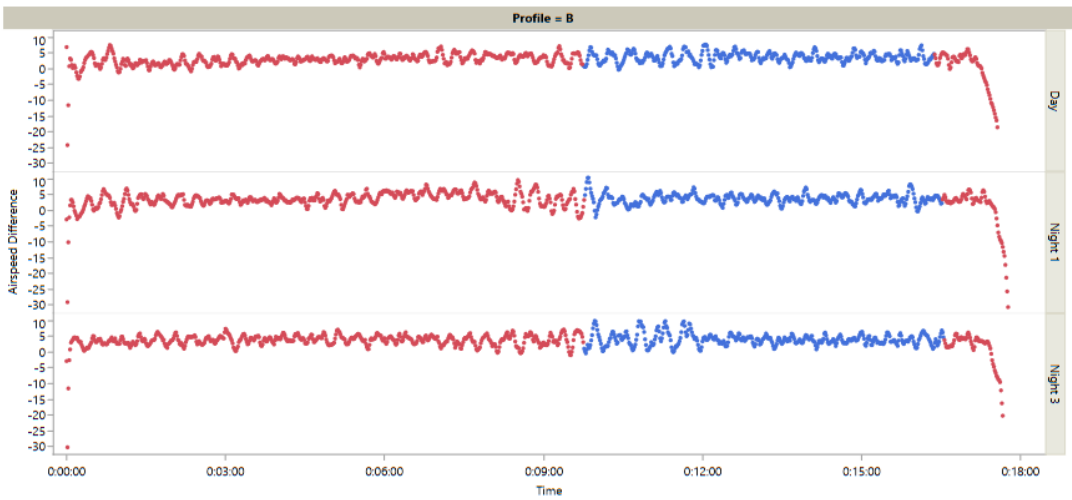
Time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Airspeed Difference
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-25
-30
Day
Night 1
Night 3
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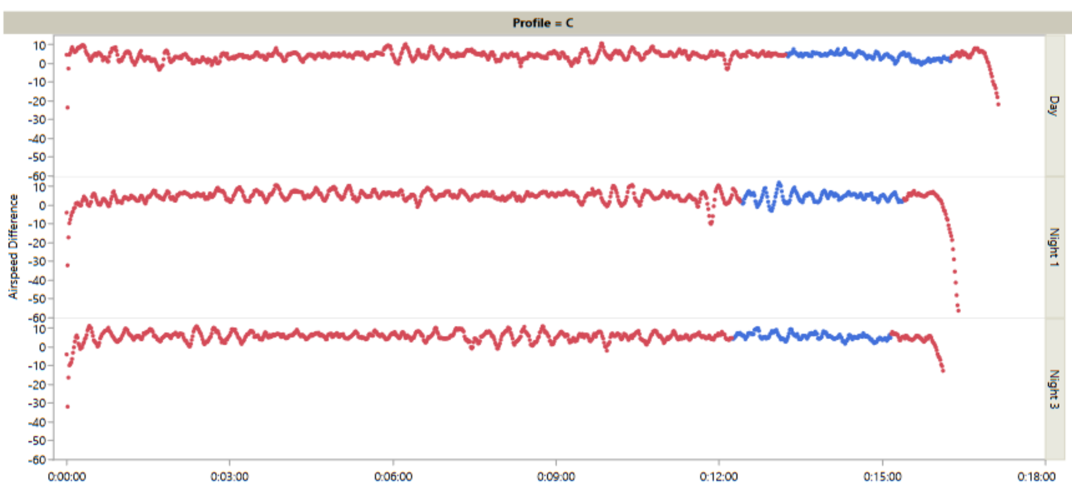
Time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Airspeed Difference
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Day
Night 1
Night 3
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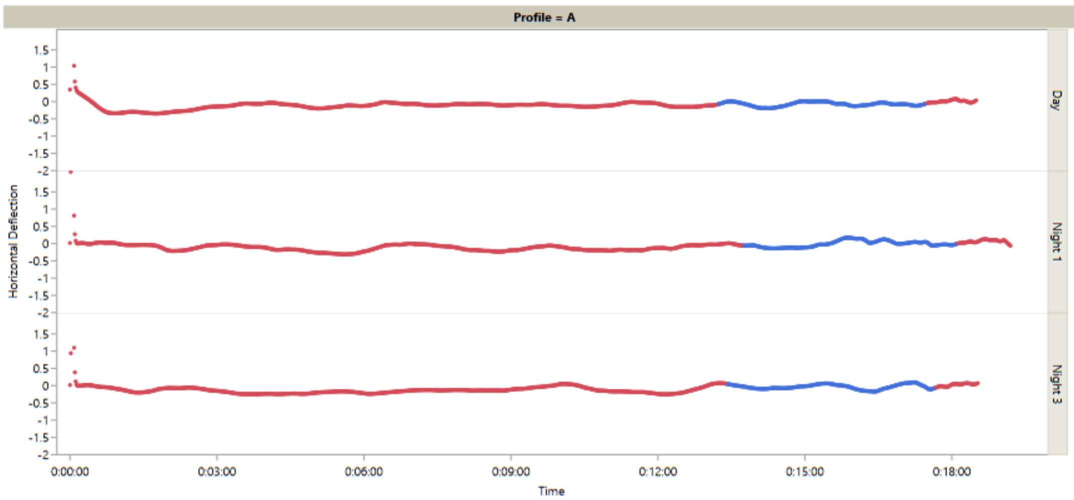
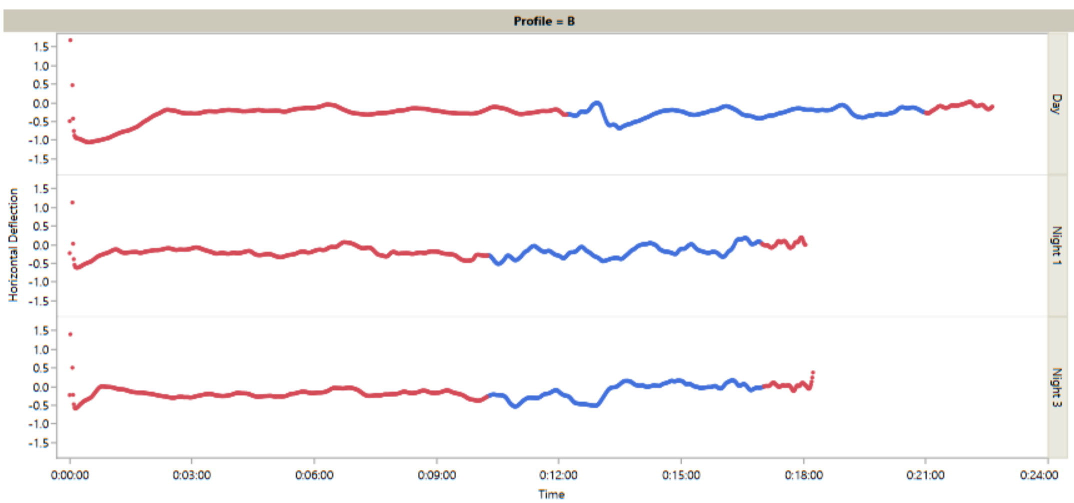
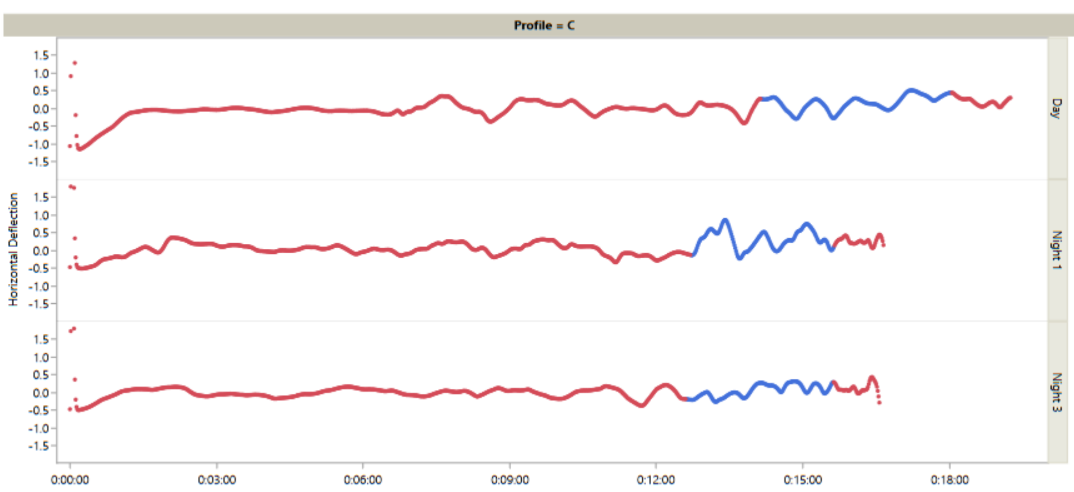
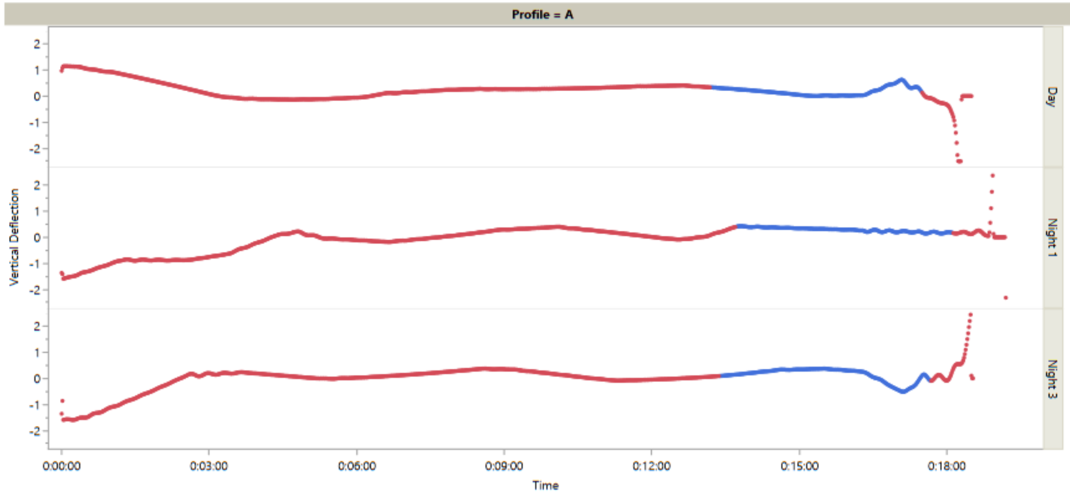
0:15:00
0:18:00
Time

8. Participant 9








Profile = A
Vertical Deflection
Day
Night 1
Night 3
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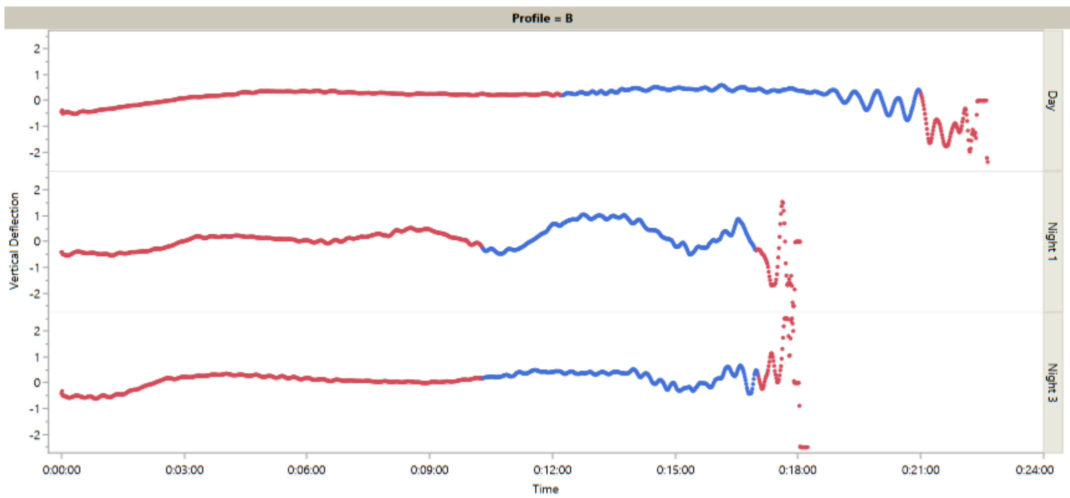
0:09:00
0:12:00
0:15:00
0:18:00
Time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Night 1
Night 3
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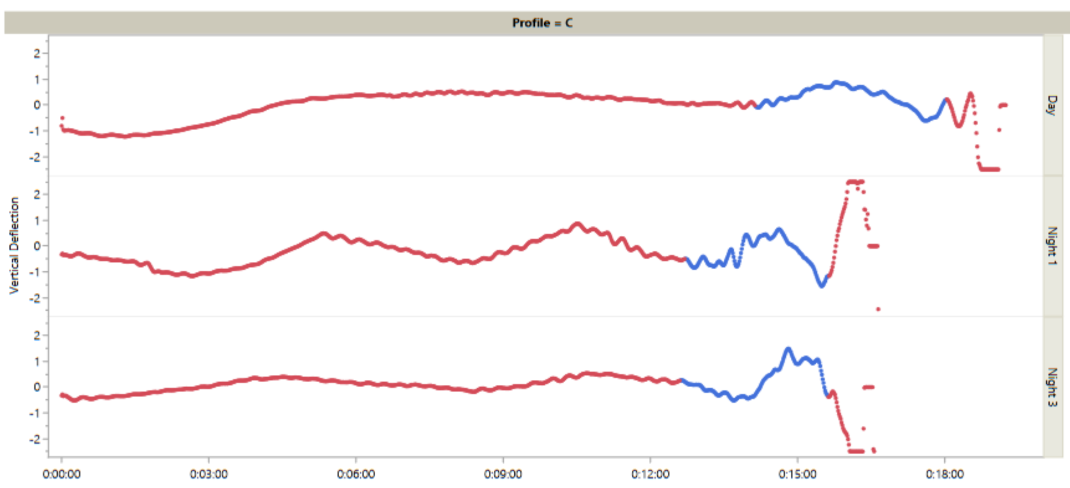
Time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Vertical Deflection
Day
Night 1
Night 3
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0:03:00
0:06:00
0:09:00
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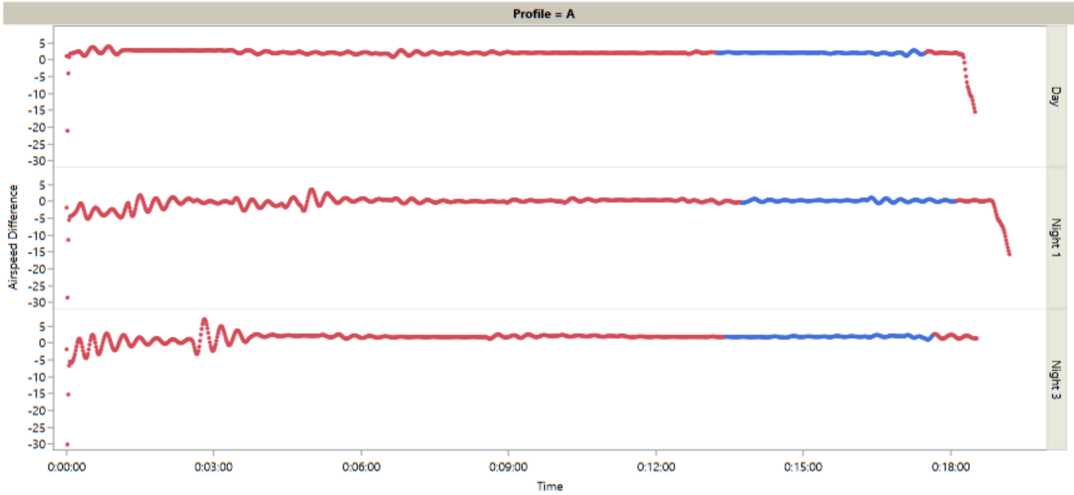
Time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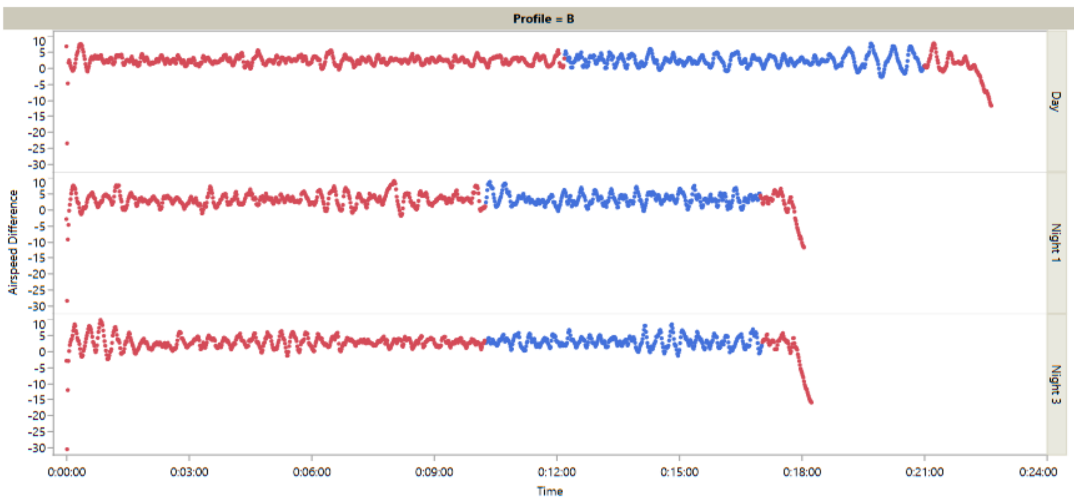
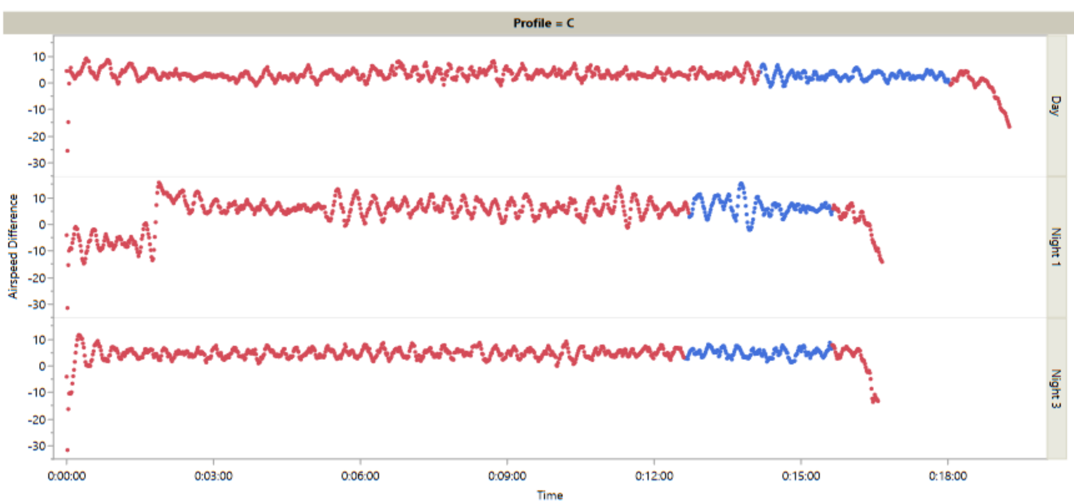
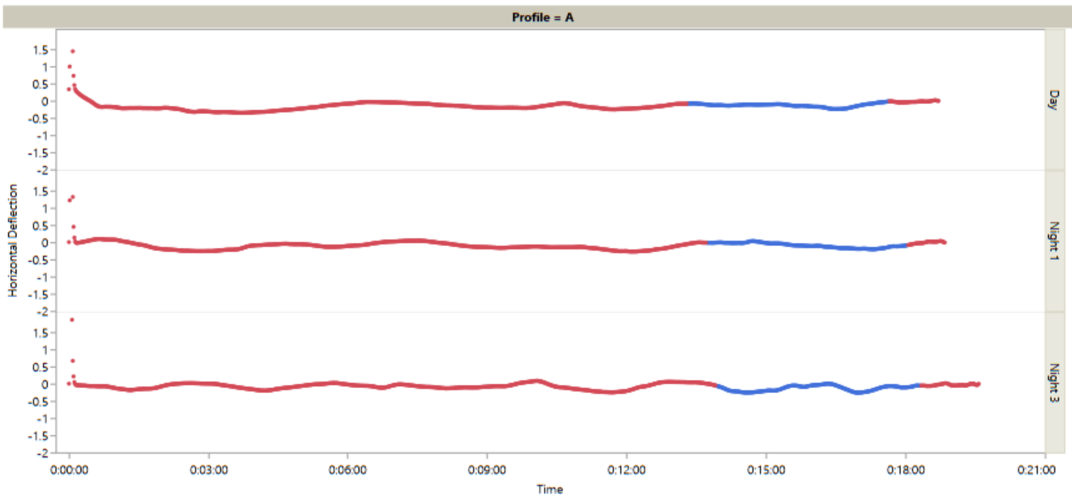
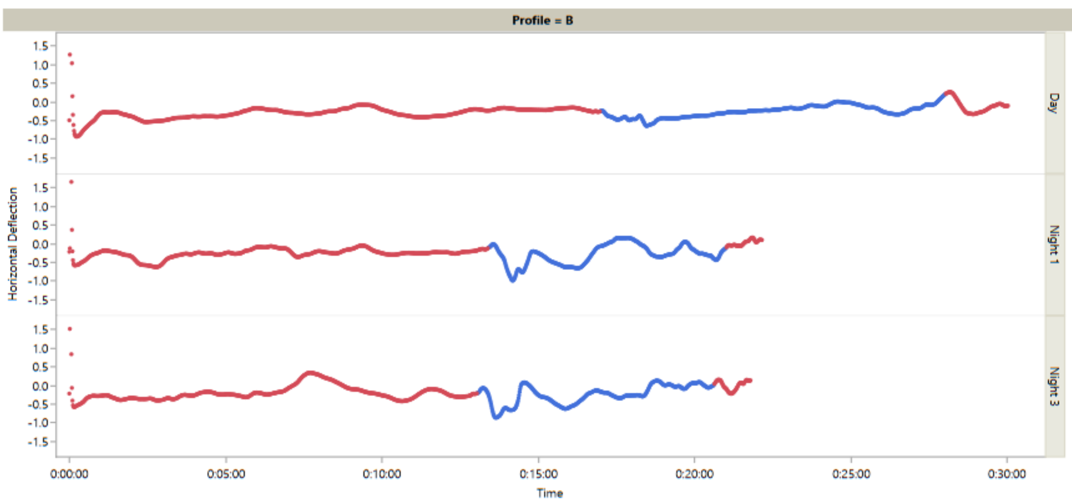
Airspeed Difference
Day
Night 1
Night 3
Time

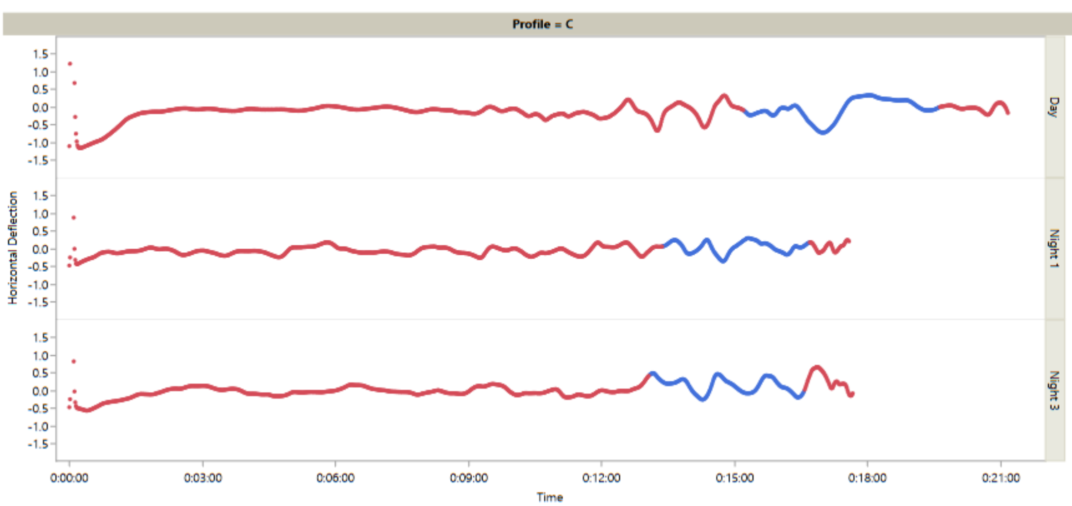

Profile = B
Airspeed Difference
Day
Night 1
Night 3
Time

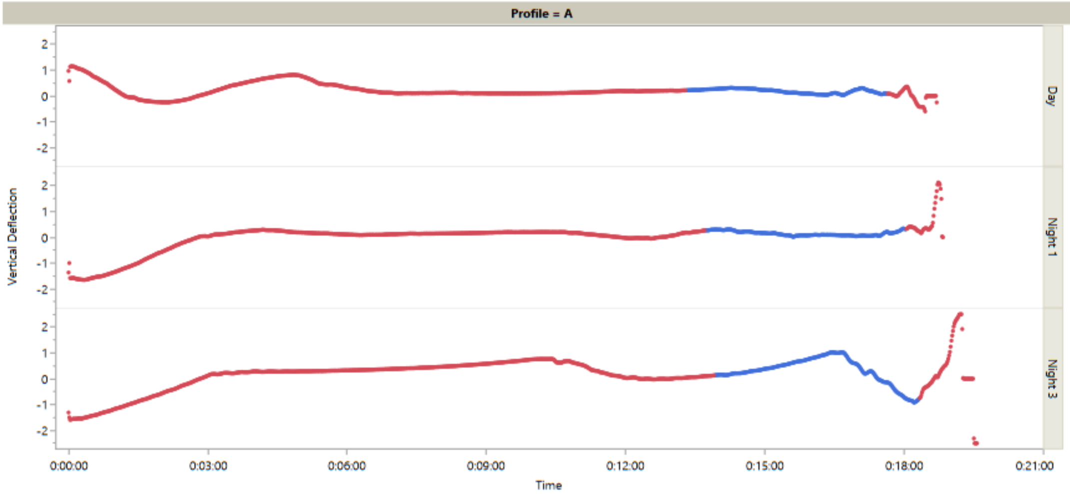

Profile = C
Airspeed Difference
Day
Night 1
Night 3
Time

9. Participant 10








Profile = A
Vertical Deflection
Day
Night 1
Night 3
2
1
0
-1
-2
0:00:00
0:03:00
0:06:00
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0:12:00
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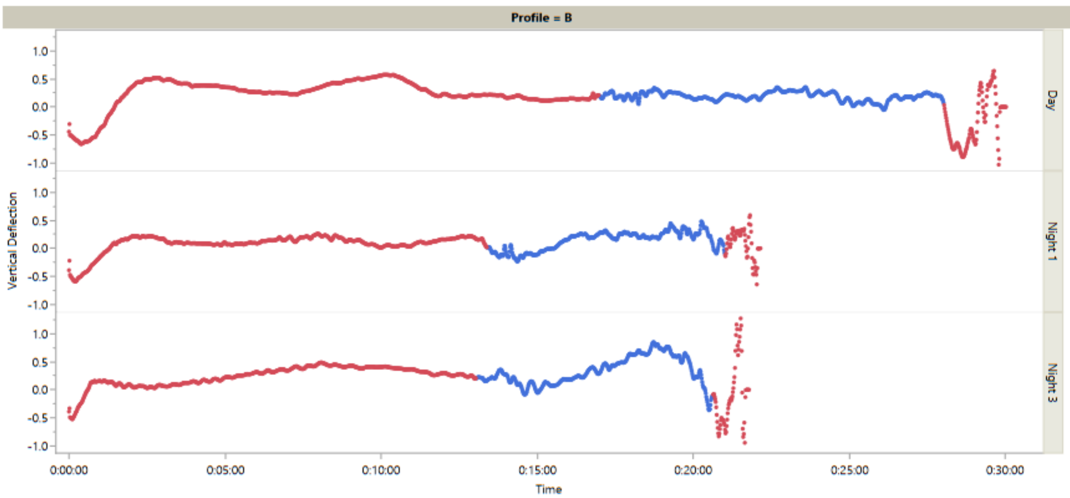
0:18:00
0:21:00
Time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Vertical Deflection
Day
Night 1
Night 3
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0.5
0.0
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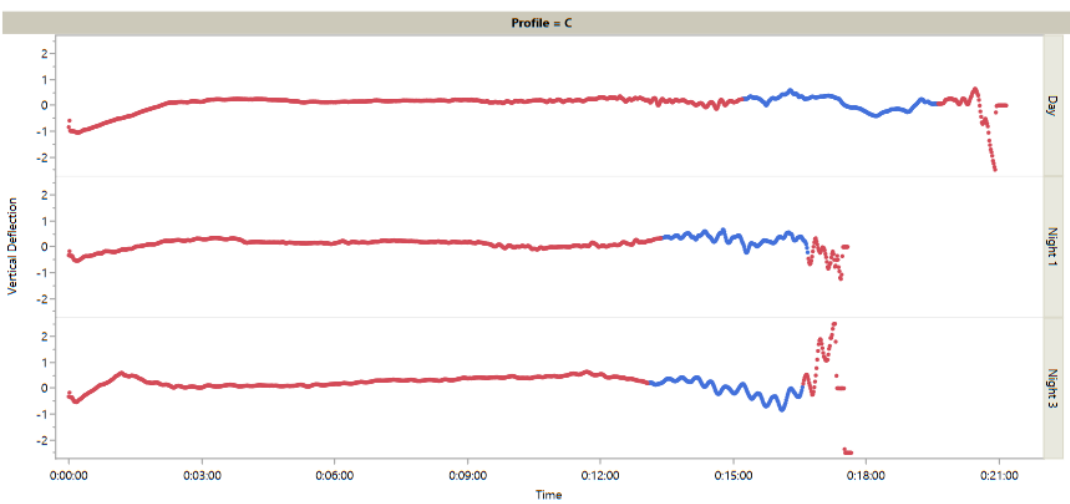
0:15:00
0:20:00
0:25:00
0:30:00
Time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Vertical Deflection
Day
Night 1
Night 3
2
1
0
-1
-2
0:00:00
0:03:00
0:06:00
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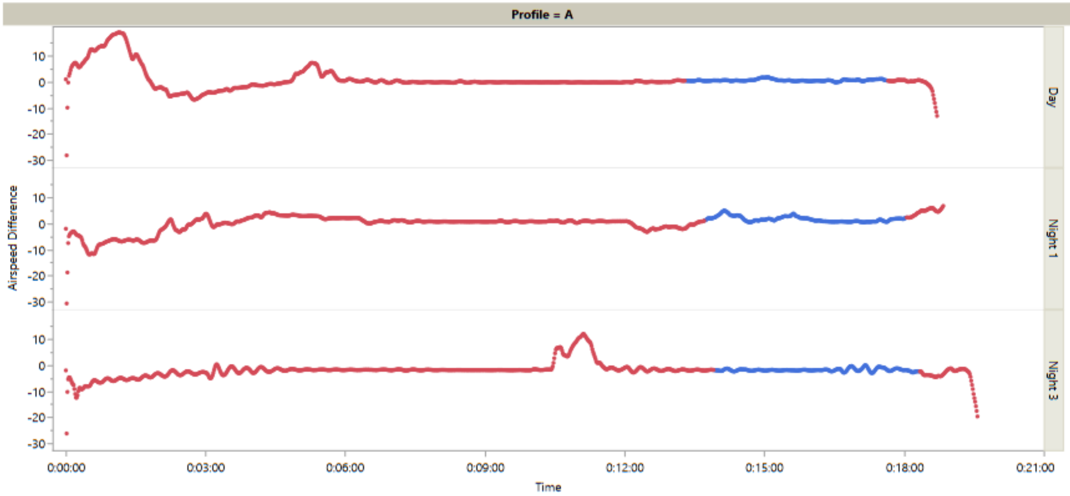
0:18:00
0:21:00
Time


Profile = A
Airspeed Difference
Time
Day
Night 1
Night 3
10
0
-10
-20
-30
0:00:00
0:03:00
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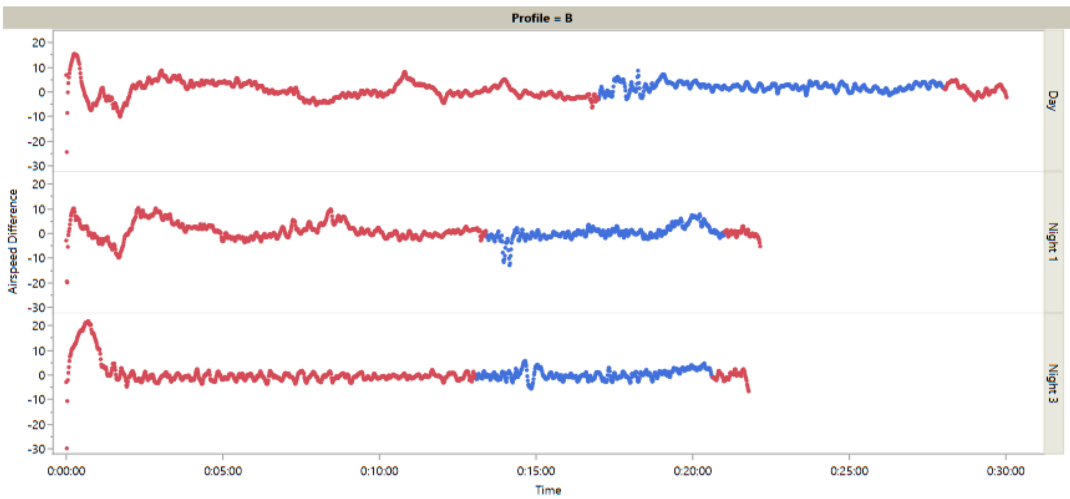
0:18:00
0:21:00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Airspeed Difference
Time
Day
Night 1
Night 3
20
10
0
-10
-20
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0:00:00
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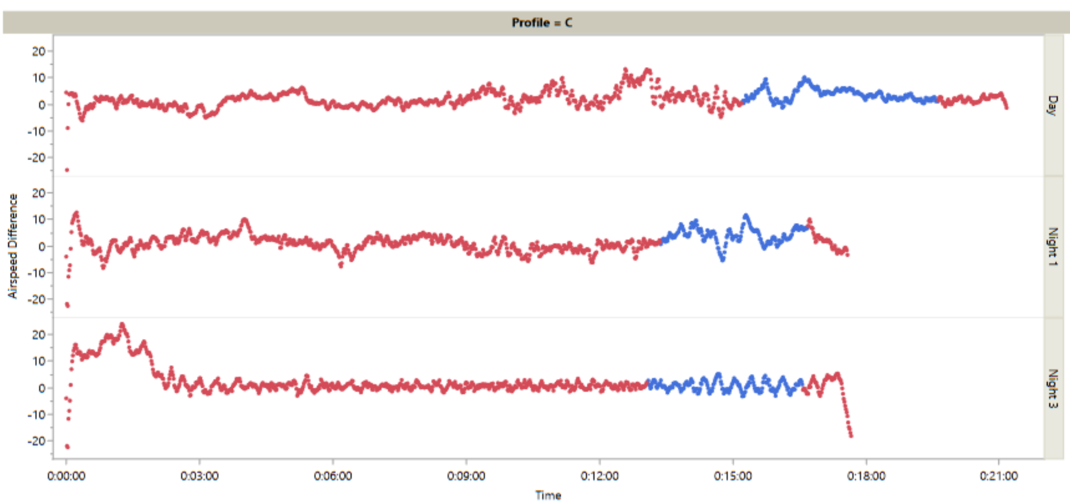
0:30:00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Airspeed Difference
Time
Day
Night 1
Night 3
20
10
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-10
-20
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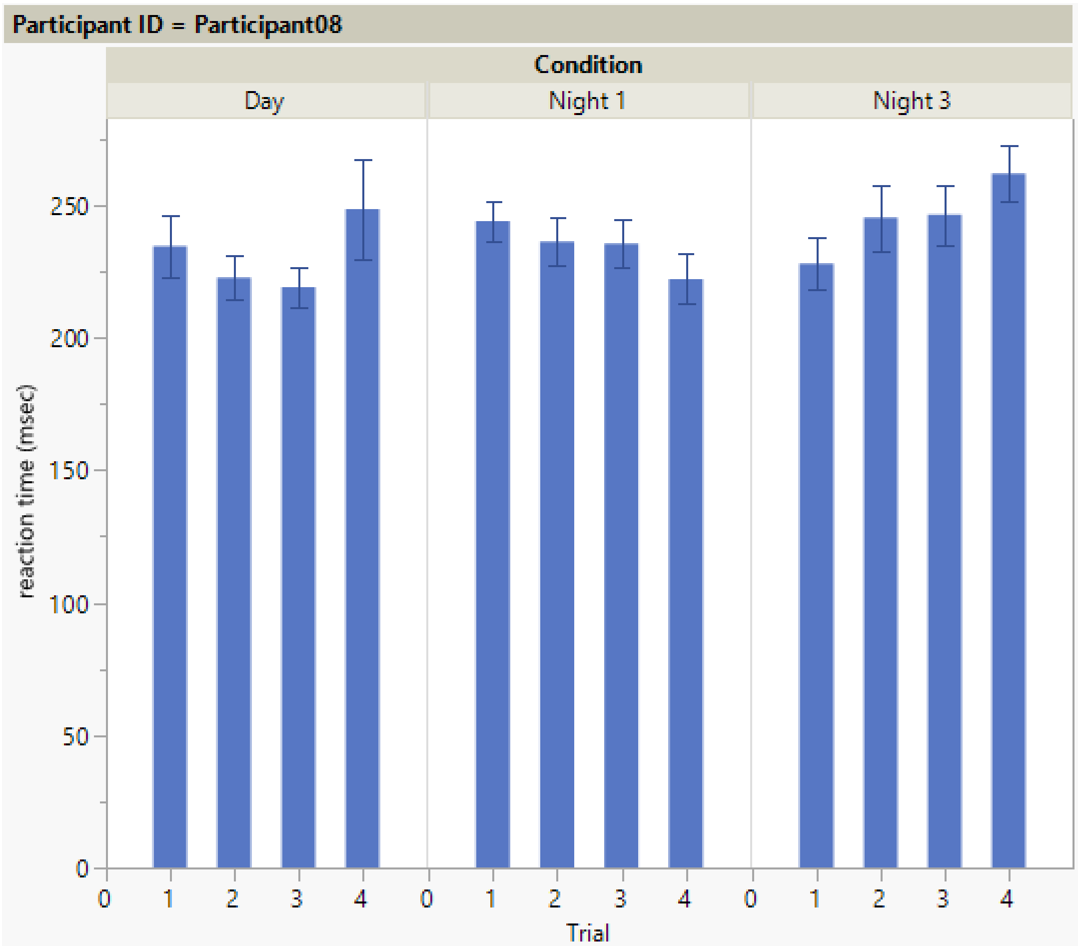
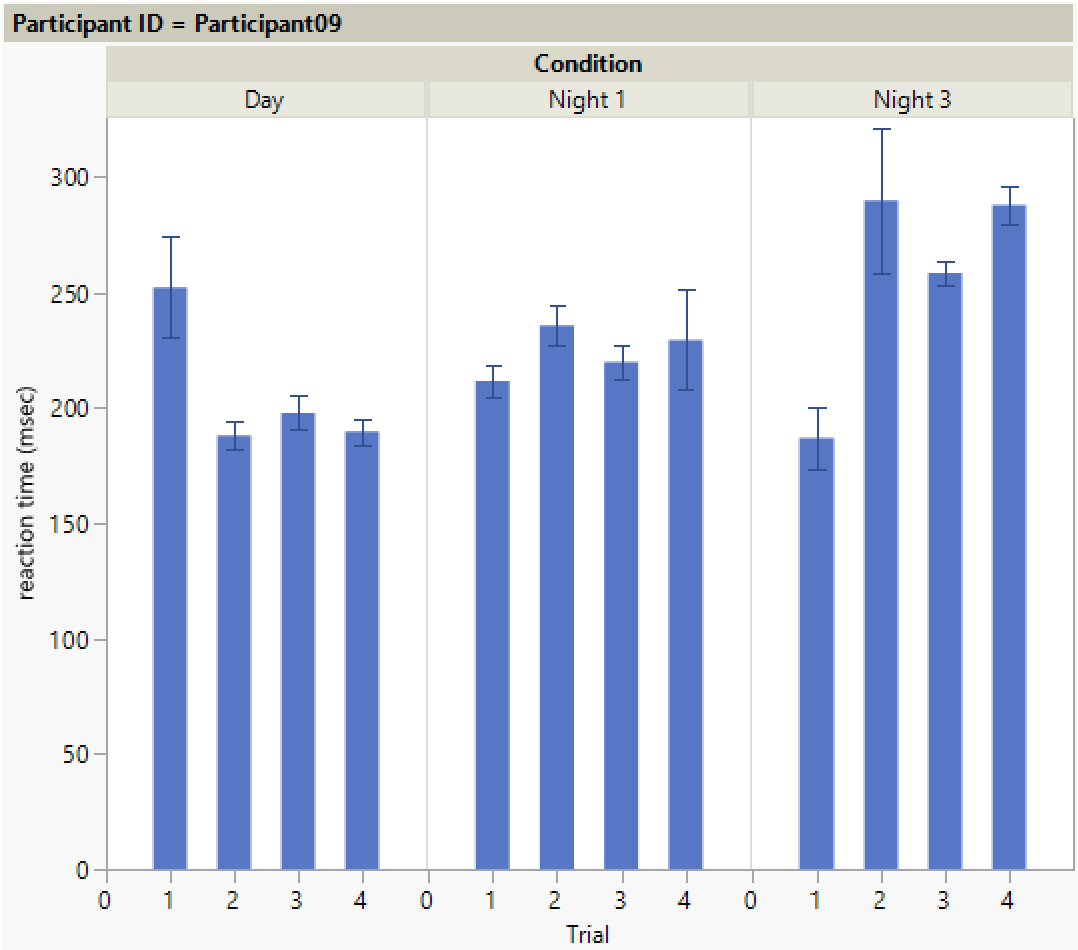
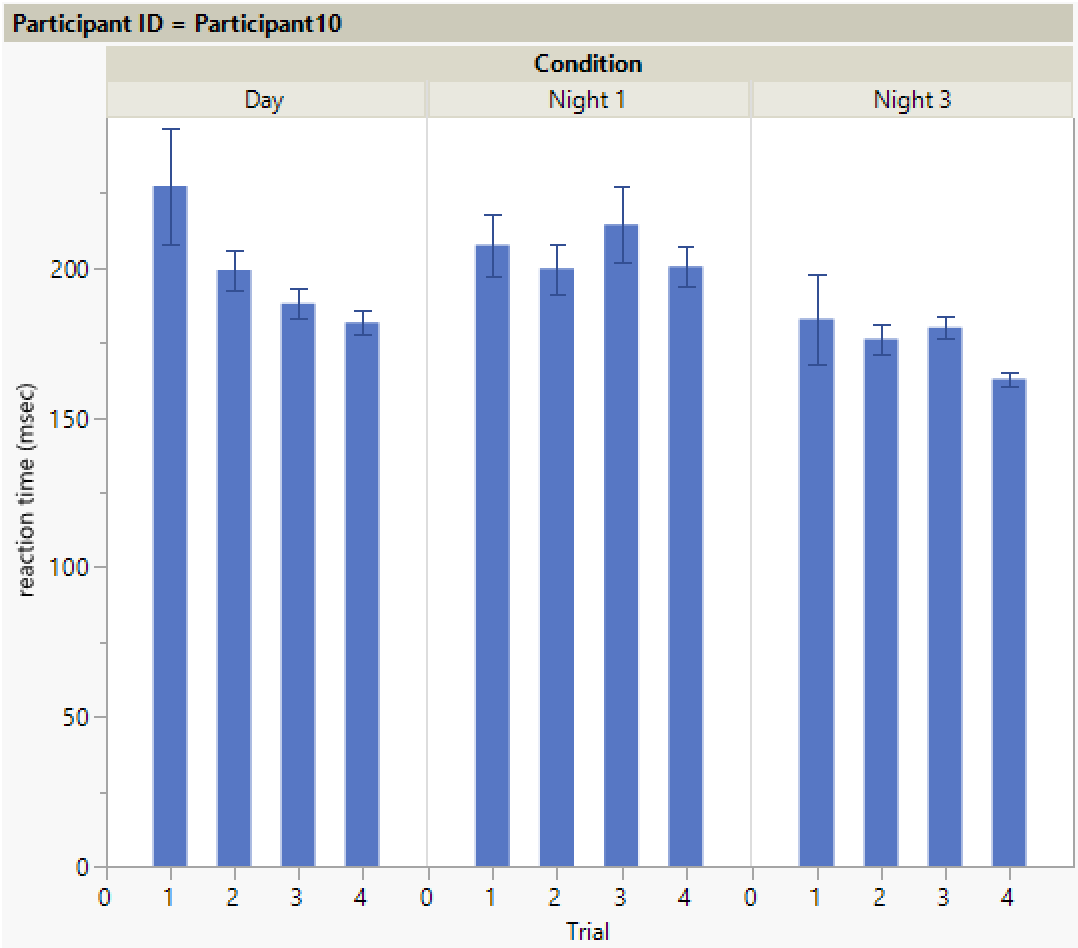
0:21:00

APPENDIX D. PVT DATA




Participant ID = Participant09
Condition
Day
Night 1
Night 3
300
250
200
150
100
50
0
reaction time (msec)
0
1
2
3
4
0
1
2
3
4
0
1
2
3
4
Trial



Participant ID = Participant10
Condition
Day
Night 1
Night 3
reaction time (msec)
0
50
100
150
200
0
1
2
3
4
Trial

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