A Methodology for Detecting Pilot Fatigue and Head Tilt Measured Using Flight Simulation of an Unmanned Aerial Vehicle

by

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Abstract

The objective of this research project was to determine whether the human factors of fatigue and head tilt can be detected in real time by measuring the head motion of pilots flying simulated unmanned aircraft missions. Test subjects flew a set of maneuvers using a fixed-base flight simulator programmed with a General Atomics MQ-1 Predator UAV simulation, while an infrared tracking system tracked the six-degree-of-freedom motion of their heads. Test subjects completed three sessions of data collection. The data collected was date, time, translational motions of x, y, and z, and rotational motions of yaw, pitch, and roll. The collected data was then tabulated and plots of the six-degrees-of-freedom versus time were generated for analysis. Visual observations of the subjects' head motion during the session were compared to the plotted data. Analysis of the data collected supports the conclusion that motions in translational y and rotational pitch are the most promising indicators of fatigue. On the other hand, rotational motions consisting of coupled yaw and roll appear to be the best indicators of head tilt. Due to the limited amount of data, these conclusions are preliminary. However, the methodology presented for observing evidence of phenomena, such as pilot fatigue and head tilt, show considerable promise.

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May the Force Be With You.

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Chapter 1

Introduction

With the increased use of unmanned aerial vehicles (UAVs) in the U.S. military and other federal and state agencies, i.e. Border Patrol, Treasury, Agriculture, Commerce, *et al.*, as well as the upcoming expectancy of their use in commercial airspace, human factors affecting UAV pilots has become an important topic of discussion. Unlike the traditional aircraft pilot, a UAV pilot is flying the aircraft from a base station on the ground or in another vehicle miles away from the location of the actual aircraft. This change in environment is a new way of operating for the traditional pilot. Generally, the view from the UAV's nose camera is portrayed on the screen along with the instrumentation of a conventional aircraft. However, much of the intuitive feel a pilot gains from sitting in an aircraft during flight is lost due to the lack of vestibular and haptic cueing[1]. This is a similar scenario that occurs when a pilot is "flying" a fixed-base flight simulator. As a result of this similarity, it is postulated that methods for detecting human factors affecting pilots during a simulator session can be applied to pilots flying a UAV where action can be taken to prevent an accident in real time. By using an infrared head tracking system, the primary interest of this study is two human factors associated with head motion: fatigue and head tilt.

The first human factor of interest, fatigue, is prevalent in UAV flight and believed to be the cause of multiple crashes upon landing[2]. Fatigue is defined by the Federal Aviation Administration (FAA) as, "a condition characterized by increased discomfort with lessened capacity for work, reduced efficiency of accomplishment, loss of power or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness[3]." A UAV pilot's work schedule differs markedly from that of a traditional pilot, and awareness of this challenge is increasing as F-15 pilots are transferred to UAV Training and Operations[4].

Studies have also shown that continuous viewing of computer screens puts stress on the eyes of the operator and cause the operator to become fatigued[1]. These factors coupled with the stress of flying a multi-million dollar aircraft that cannot be seen or touched during a mission, makes a UAV pilot's situation unique.

Because of its association with head motion, the second human factor of interest is head tilt. Head tilt is a medical condition similar to torticollis, a twisting of the neck with the head tipped to one side and the chin to the other[5]. Also, the term head tilt is hypothesized to be an optokinetic reflex, a condition of the inner ear that causes a subject to misjudge the direction of line of sight from the subject to a point or the orientation of an observed object[6]. Thus, motion of the head during flight may be related to head tilt through subjects trying to compensate for these conditions. Currently in aviation medicine, there is no formal medical description for the head motion associated with head tilt, but previous research has shown that it is indicated by a yawing and rolling motion of the head[7].

In this work, the objective was to determine the head motions indicative of fatigue and head tilt. Infrared tracking technology was used as the method for data collection to measure the six-degree-of-freedom (6DOF) motion of the test subject's head, see Figure 1.1. Since this information could provide useful for unmanned aviation systems operators, ground based operations of the General Atomics MQ-1 Predator UAV were simulated. The simulation was flown by volunteer test subjects who held at least a Federal Aviation Administration Private Pilot Certificate. The Master Set of maneuvers flown by the test subjects represent a typical UAV mission along with particular maneuvers that would allow further observation of fatigue and head tilt. Three sessions for each test subject were conducted to provide replicate data. In Chapter 2, background information is provided on past studies of detection and measurement of fatigue and head tilt as well as information on UAVs and their associated human factors. In Chapter 3, the instrumentation used in the study is presented, while Chapter 4 presents the protocol used during the simulator sessions. In Chapter 5, the results of the study are summarized, and in Chapter 6, conclusions are discussed and recommendations are made for future study. The human subject protocol for this research was approved by the Auburn University Institutional Review Board (12-082 EP1203), see Appendix A.

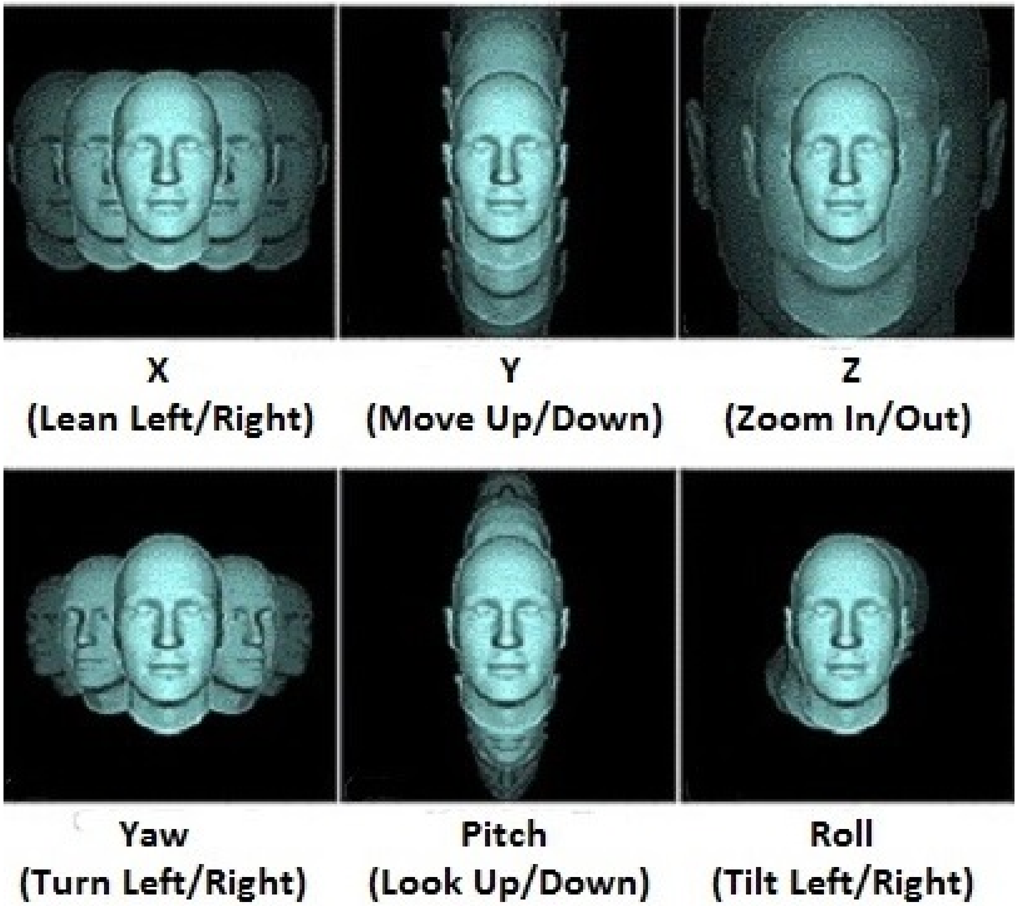


Figure 1.1: The Six Degrees of Freedom[8]

Chapter 2

Review of Literature

According to Wiegmann and Shappell[9], “pilot fatigue is difficult to observe directly, much less quantify.” As a result, the aeromedical perspective in their “Human Factors Analysis and Classification System[9]” defines pilot and flight crew fatigue as a cause of aircraft accidents not just a contributing factor. The FAA agrees with this view and describes fatigue as a result of many factors pertaining to sleep including: the amount of recent sleep a crew member has received; the number of continuous hours awake; a crew member’s accumulated sleep debt and work load; the time of day of the crew member’s flight; and the number of time zones to be crossed[10]. The FAA has developed specific criteria for airline pilots and crew members in order to reduce the risk of fatigue occurring during aircraft operations. A summary of the factors associated with pilot fatigue is offered by Caldwell[11], and some of the methods used to study these factors and determine the FAA’s fatigue prevention criteria are provided by Rosekind[12], Van Dongen[13], Frakes[14], and David[15]. The FAA is focused on using this information to prevent fatigue indirectly rather than trying to detect fatigue and provide a remedy in real time before an accident occurs.

2.1 Fatigue Detection

In medicine, fatigue is defined as “a non-pathologic state resulting in decreased ability to maintain function or workload due to mental or physical stress[16].” Currently, detecting fatigue in commercial truck drivers in the transportation industry is an ongoing activity[17][18][19][20]. There are many driver fatigue detection techniques that can be divided into two broad categories: techniques that monitor the driver directly and techniques that monitor the driver’s operation of the vehicle[21][22]. Techniques that monitor the driver directly include intrusive measuring of brain waves, heart rate, and/or pulse. However, intrusive measures require sensors to be attached to the driver that cause discomfort. Therefore, more research is focusing on non-intrusive measures such as: eye tracking, eyelid movement, gaze tracking, head movement, and facial movement. Techniques that monitor the vehicle include measuring the vehicle's speed, lateral position, turning angle, and/or moving course. The most established driver fatigue detection technique used is the monitoring of eye movement.

Preliminary research using head tracking to detect fatigue in commercial truck drivers has been conducted by Xie[23], Smith[24], and Ji[25]. The most recent study by Ji proposes that nodding of the head indicates the onset of fatigue. By using an established eye tracking technique, the frequency of nods a subject experiences over time can establish a given fatigue level. This technique uses the distance between the eyes and the eyes' locations as inputs to a Kalman filter algorithm in order to predict where the face is located in the image. A conclusion drawn from this research is that the given algorithm could estimate the orientation of the head and resulting number of nods accurately. However, a criterion for indicating levels of fatigue that correspond to the number of nods experienced has not been established.

2.2 Head Tilt

In 1960, Greenberg[36] published a short article theorizing that there was a correlation between eye dominance and head tilt. In the 1990s, research was performed by Dr. Fred H. Previc at Brooks Air Force Base to determine this relationship between eye dominance and head tilt. He sought to prove Greenberg's hypothesis that vertical misalignment of the eyes are caused by a lateral head tilt resulting from ocular dominance. Previc's research focused on measuring a subject's sight dominance and vertical misalignment of the eyes then comparing it to two-dimensional photographic measurements of the subject's head tilt. His study demonstrated that sighting dominance is related to ocular misalignment produced by lateral head tilt and therefore predictive of head tilt in most subjects[37][38]. Since Previc's research in the mid 90's, most head tilt research has focused on determining the cause of the medical condition known as torticollis, which is associated with a twisting of the neck to one side accompanied by painful muscle spasms.

In 2008, the precursor to this research study was conducted to determine motions of the head that indicate head tilt using flight simulation. After an initial round of testing to find qualified subjects without vestibular issues, non-pilots viewed a flight simulation and pilots viewed, then flew the same simulation. Data of the 6DOF head motion was collected via infrared tracking and analyzed to graphically demonstrate the head tilt observed during the flight simulation testing. As a result, Zallen *et al.*[7] determined head tilt to be indicated by not only a two-dimensional lateral rotation of the head, as shown by Previc[37], but also by a three-dimensional yawing rotation of the head. Another result of this study was the preliminary finding that fatigue was indicated by a translational y motion of the head. As a result, the current research study was established to determine further information on the indicators of fatigue and to give further conclusion to the findings that head tilt is indicated by rolling and yawing motions of the head.

2.3 Unmanned Aerial Vehicles

With the invention of the modern flight simulator, flight simulation was used extensively in the aviation industry to train pilots and flight crew along with assisting in aircraft design and development as well as human factor and ergonomics issues. Besides the precursor to this study[7], other head-tracking research using flight simulation has focused on spatial awareness during flight. Pilots have to interact with a complex system through a human-machine interface that must be monitored frequently and systematically. By monitoring a trainee's eye and head motion during a simulation exercise, an instructor can give feedback on the level of the trainee's awareness and where he needs to improve his monitoring[26]. Currently, the concept of flight simulation has been remodeled into a ground control station for remotely flying UAVs.

2.3.1 General Atomics Predator

The General Atomics Predator has two designations, MQ-1 and RQ-1. The General Atomics MQ-1 Predator, shown in Figure 2.1, is weaponized to conduct offensive operations, irregular warfare, and high value target and individual prosecution. Typically, a laser-guided AGM-114 Hellfire missile will be mounted under each wing, however, armament varies upon the nature of the target and could include a Singer air-to-air missile, Brilliant Anti-Tank (BAT) ammunition, or the Small Diameter Bomb (SDB). The General Atomics RQ-1 Predator, shown in Figure 2.2, is not weaponized, but it is tasked with long endurance, medium altitude surveillance and urban reconnaissance missions. It is equipped with a Northrop Grumman AN/ZPQ-1 Tactical Endurance Synthetic Aperture Radar (TESAR) and a Wescam Versatron 14TS Infra Red/Electro-Optical (IR/EO) sensor turret[27]. The Predator has a Rotax 914F four cylinder engine with 115 horsepower. It has a wingspan of 55 feet (16.8 meters), length of 27 feet (8.22 meters), and height of 6.9 feet (2.1 meters). The Predator has an empty weight of 1,130 pounds (512 kilograms) with a maximum takeoff weight of 2,250 pounds (1,020 kilograms) corresponding to 665 pounds (100 gallons) of fuel and 450 pounds (204 kilograms) of payload. Cruise speed is around 84 mph (70 knots) with speeds up to 135 mph (117 knots), range of 770 miles (675 nautical miles), and a ceiling of 50,000 feet (15,240 meters)[28]. The Predator unit cost was approximately $4 million in fiscal year 2010 dollars[29]. However, the Predator is part of an Unmanned Aircraft System (UAS) that consists of four sensor/weapon equipped aircraft, a ground control station (GCS), a Predator Primary Satellite Link (PPSL), and spare equipment along with operations and maintenance crews for deployed 24-hour operations, which cost approximately $20 million in fiscal year 2009 dollars[30].

2.3.2 UAV Human Factors

With the increased use of UAVs, attention has been turned to the human factors associated with being a UAV pilot[32][33][34]. There are two main human factors issues associated

Figure 2.1: General Atomics MQ-1 Predator[31]

Figure 2.2: General Atomics RQ-1 Predator[31]

with UAVs that can lead to fatigue and be amplified by a pilot's head tilt, ergonomic interface issues and control issues. The ergonomics design of the operation station is the main point of complaint from UAV pilots including the heads-up-display (HUD), seat design, and control layout. Two medical issues attributed to bad ergonomic design that UAV pilots experience are lumbar kyphosis and computer vision syndrome (CVS). Lumbar kyphosis is a problem that occurs at the musculoskeletal level when one sits for an extended period of time and the lumbar region of the back flattens out or bends outward which results in discomfort and a lack of productivity[1]. CVS is defined by the American Optometric Association as a "complex of eye and vision problems related to near work which are experienced during or related to computer use[35]." Specific problems with the original Predator setup included the HUDs, one was at eye-level and one was mounted higher up, which forced the pilot to crane his neck in order to view the screen; and the joysticks, which were elevated above the arm rest of the chair and required the pilot to lift his arms constantly in order to maneuver the aircraft. The HUD also used red graphics on a blue background resulting in further stress on the pilot's eyes. Although the Predator setup has been improved to a three monitor setup in a horizontal configuration at eye level with one joystick and keyboard at arm level with an easier to read HUD, ergonomic issues still play a role in the human factors of Predator pilots.

Besides the ergonomic interface, the loss of control due to a mediated visual field with no vestibular and haptic cueing result in a stressful environment for the a UAV pilot. The loss of vestibular and haptic cueing can cause delay in the recognition of an engine failure, ice accumulation, or approach to stall, which can result in an accident. The mediated field of view related by the UAV's nose camera can hamper the pilot's control of the aircraft. This is especially true during landing where peripheral cues are valuable, and is a potential variable in many UAV crashes that occur upon landing[2].

Chapter 3

Instrumentation

A complete system setup of the study is shown in Figure 3.1. The MGI Fixed-Base Flight Simulator is operated using Computer One. It has a three screen monitor setup for a better viewing experience, and it is equipped with Precision Pro pedals and yoke for increased control of the aircraft simulation. The infrared tracking receiver, used to measure the head motion of the subjects, can be seen mounted on the top of the middle monitor of the flight simulator's three screen configuration. The infrared tracking receiver is plugged into the rear of Computer Two and operated separately from the flight simulator software to prevent an overload of Computer One's system.

3.1 Computer One

Computer One operates the hardware and software needed to support the MGI Fixed-Base Flight Simulator, see Appendix B. It is a standard Dell Optiplex 740 Desktop with 4 GB of 1.9GHz DDR2 DRAM with an ATI Radeon 6500 graphics card. The other components of Computer One related to the study are as follows:

1. CH Flight Simulator Yoke (Model 99914) [39]
2. CH Precision Pro Pedals (Model 88785) [39]
3. Three, 19" Dell LCD Monitors (Model EI98WFPv)
4. Matrox TripleHead2Go (Model KFE5S204) [40]
5. Microsoft Windows XP Professional Version 2002 Service Pack 3 Operating System

Figure 3.1: MGI Fixed-Base Flight Simulator with Infrared Tracking Technology

6. Microsoft Flight Simulator X: Gold Edition

7. First Class Simulation's "UAV Predator" Add-on [41]

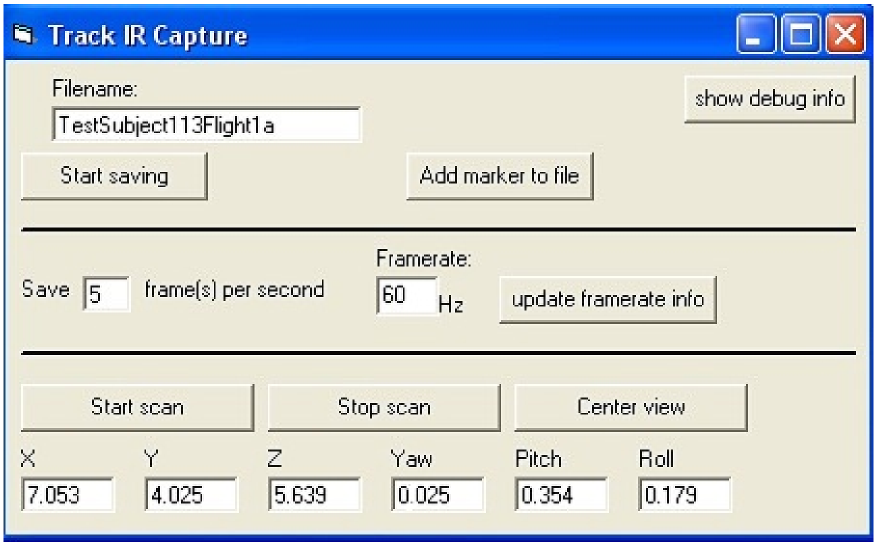
First Class Simulation's "UAV Predator" software uses the MQ-1 version of the General Atomics Predator. It is equipped with a Hellfire missile under each wing. The missiles cannot be fired during the simulation which requires the test subjects to take off and land with a missile under each wing. This is a scenario seen by UAV Predator pilots when a mission is aborted and returned to base.

3.2 Computer Two

Computer Two is a standard Hewlett Packard Compaq 8200 Elite Convertible Minitower PC with 16 GB of PC3-10600 Memory operating Microsoft Windows XP Professional Version 2002 Service Pack 3 with a NVIDEA NVS 300 PCIe graphics card. This computer operates the hardware and software needed to support the Embedded Track IR Capture System[42], see Appendix B. The TrackIR4[8], shown in Figure 3.2, is an infrared receiver, originally designed for use with gaming software, that tracks the 6DOF motion of the head. It tracks a head-mounted TrackClip[8], also shown in Figure 3.2, within a field of view of 46 degrees, a sample rate of 120 frames per second, a raw sensor resolution of 358 x 288, a sub-pixel resolution of 1/20th pixel, reporting resolution of 7100 x 5760, and a horizontal resolution of 154 sub-pixels per degree.

The TrackIR4 is mounted atop the center of the three LCD monitor configuration of Computer One and connected to a USB 2.0 port on the rear of Computer Two. Data is recorded on Computer Two using the TrackIR Capture software, shown in Figure 3.3, as the test subject flies the UAV Predator simulation on Computer One. The triangular shape of the three reflective phosphor markers on the TrackClip is key to having vectors for the TrackIR4 to measure the difference in position and orientation over time via infrared signals, see Figure 3.4. The distances read by the TrackIR4 to form this vector are the three sides of the triangle formed by the phosphor markings along with the distance from the top most marker to the plane of the bottom two markers.

Figure 3.2: TrackIR4 and TrackClip[8]



Filename: TestSubject113Flight1a

Save 5 frame(s) per second

Framerate: 60 Hz

X	Y	Z	Yaw	Pitch	Roll
7.053	4.025	5.639	0.025	0.354	0.179

Figure 3.3: Visual of the TrackIR Capture Software[42]

Figure 3.4: TrackIR4 Reading Position and Orientation via TrackClip[8]

Chapter 4

Test Subject Flight Details

The Master Flight containing eighteen maneuvers was performed by Kay[43], a Federal Aviation Administration Certified Flight Instructor. The Master Flight has a duration of 76 minutes and 24 seconds. The Master Set of eighteen maneuvers in the Master Flight to be performed by each test subject follows:

1. Take off and ascend to 20,000 feet.
2. Initiate a standard rate turn to the left for 180 degrees of heading change.
3. Level flight at 20,000 feet for 7 minutes.
4. Descend to 3,000 feet and level off.
5. Initiate a standard rate turn to the right for 180 degrees of heading change.
6. Ascend to approximately 4,000 feet.
7. Descend back to 3,000 feet.
8. Complete a 360 degree level turn to the right at 40 degrees of bank.
9. Complete a 360 degree level turn to the left at 40 degrees of bank.
10. Complete a 360 degree ascending turn to the right at 35 degrees of bank.
11. Complete a 360 degree ascending turn to the left at 35 degrees of bank.
12. Complete a 360 degree descending turn to the right at 35 degrees of bank.
13. Complete a 360 degree descending turn to the left at 35 degrees of bank.

14. Begin a standard landing pattern and land the aircraft.
15. Taxi down the runway for five seconds and then take off.
16. Climb to approximately 1,800 feet.
17. Repeat steps 14, 15, and 16, until five landings have been completed.
18. After the fifth landing, the simulation is complete.

4.1 Test Subject Characteristics

Test subjects were recruited from the student population at Auburn University as well as from the general population in the surrounding area. It is noted for the study, that the student/lesser experienced pilots have more current simulator experience than the older/more experienced pilots recruited from the general population. There were a total of thirteen test subjects who flew for the study. Nine of the test subjects were between the ages of 20-27 and the other four between the ages of 55-70. All test subjects were male as a result of a lack of interest in the study from the female pilots recruited.

4.2 Test Subject Calibration

Each test subject's head was zeroed before a flight simulator session began. This procedure was accomplished with a horizontal and vertical Cen-Tech Self-Leveling Laser Level Item 92703[44] located immediately behind the flight simulator seat. The laser has maximum power of 5 mW, Class IIIA Protection, and has a wavelength of 650 nm +/- 10 nm. Calibration establishes standardized tracking between the TrackIR4 and the TrackClip by performing the five steps that follow:

1. The participant is seated at the flight simulator with the Cen-Tech Laser Level mounted 37.5 inches to the rear of the seat. The Cen-Tech Laser Level is calibrated using the blue LED light located dead center on the middle monitor of the flight simulator.

2. The calibrated laser controlled with a level and rotating bezel is focused on the test subject's position to establish zero motion, as shown in Figure 4.1.

3. On Computer Two, the TrackIR Capture Program shows a Control Menu with commands and recording slots for 6DOF.

4. All recording slots are reset to zero at the beginning of every session.

5. The TrackIR4 receiver has three colored status LED's: red - no signal is received and paused; orange - signal received and paused; green - signal received and running. In order to begin recording, the green LED must be illuminated to receive and record all data.

Figure 4.1: Cen-Tech Self-Leveling Laser Level Setup

4.3 Assignment of Tasks

The test subjects meet for three sessions. The duration of the first session is two hours, and the duration of the last two sessions is one and a half hours. All three sessions require the test subjects to fly the Master Set of maneuvers described previously. However, the test subject's orientation to the flight simulator in the first session requires a slightly different process than the final two sessions.

4.3.1 Simulator Sessions

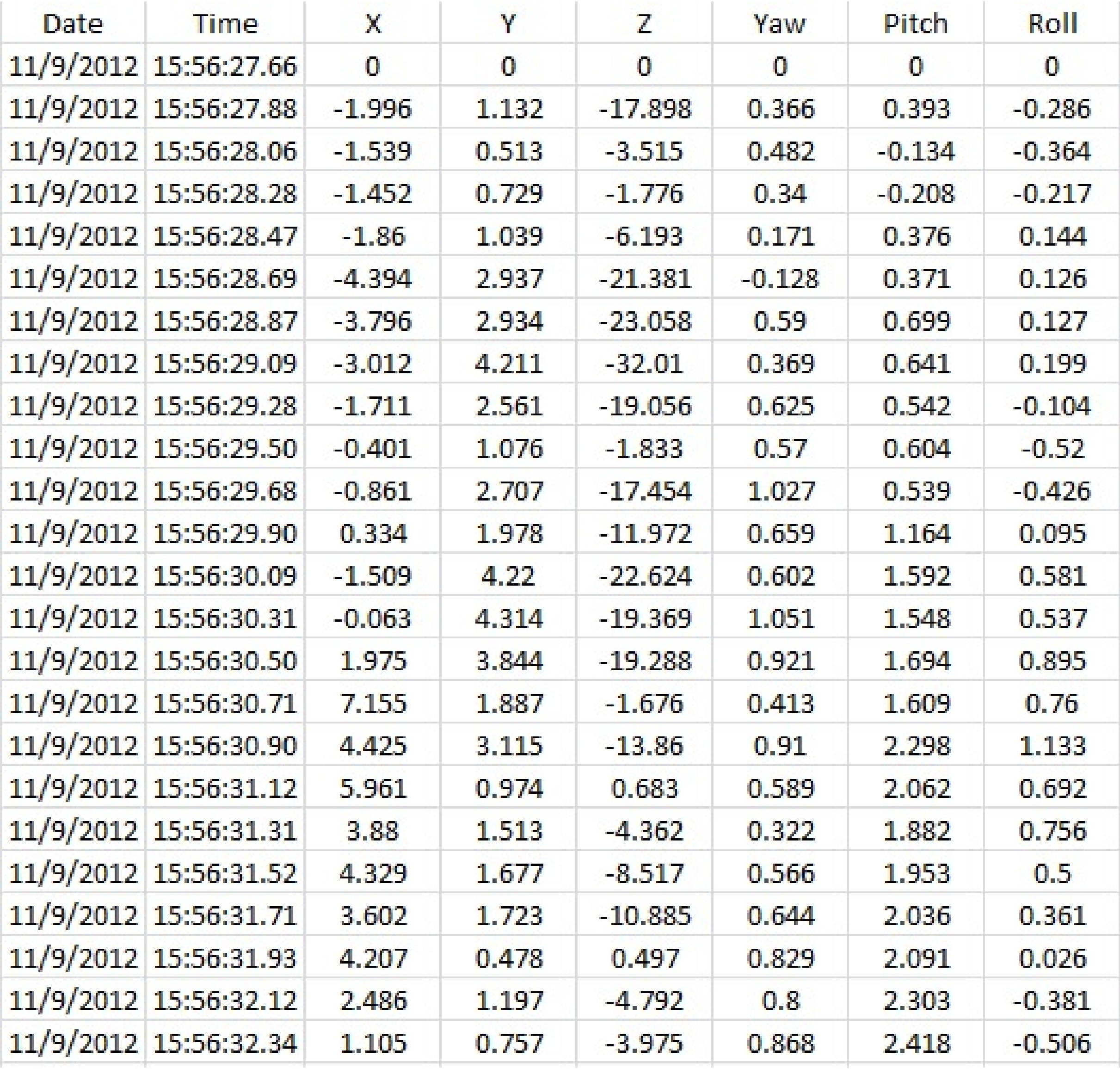
At the beginning of the first session, each test subject is shown a sheet listing the Master Set of maneuvers they will be asked to perform. Next, they are seated at the simulator and calibrated, as described in Section 4.2. The first task is viewing a 15 minute and 53 second video splice of the Master Flight that includes: initial take off, one ascending 360 degree turn, one descending 360 degree turn, and the final two landings. This allows the test subject to become familiar with the Predator simulation interface without having to worry about flying the aircraft. After the video, the test subject can ask questions about the setup and then practice flying the UAV Predator simulation until they are confident in their handling of the aircraft. Once confident, the test subject will fly the Master Set of maneuvers with data collection. The final two sessions simply consist of practice time and the flying of the Master Set of maneuvers with data collection. Temperatures at the MGI Flight Simulator were recorded for every session with an infrared precision digital thermometer. The range of temperatures during the session was 79.1°F (26.2°C) - 85.6°F (29.8°C) for all test subjects.

4.3.2 Modifications to Microsoft Flight Simulator X

After six sessions, it became apparent that there was an issue with the interface between the test subject and the simulation. Analysis of the data showed that yawing to the right was occurring with a higher frequency than assumed normal. It was determined that the original placement of the instrument panel in the simulation was not easily visible because of its small size and location at the bottom of the right most screen in the three monitor setup. As a result, the panel was enlarged and moved to the center[45], see Appendix C. Another change made during the study resulted from the observation that the manner in which some test subjects were landing the aircraft would have resulted in a crash in the real world. However, the simulation was not detecting and depicting a crash. Subsequently, the crash function in Microsoft Flight Simulator X was enabled to increase the reality of the simulation.

4.4 Data Acquisition

After the test subject has been zeroed, the test examiner will simultaneously start the TrackIR Capture Program on Computer Two and a stopwatch, then instruct the test subject to start the engines and begin the first maneuver. The test subject will indicate when that maneuver is complete, and the test examiner will mark the time on the stopwatch and instruct the test subject to begin the next maneuver until the test subject has completed the entire Master Set of maneuvers. The Embedded TrackIR Capture System converts the test subject's head motion collected by the TrackIR4 into: the date, time in one-hundredth of a second, translational parameters of 6DOF x, y, and z in one-thousandth of a millimeter, and rotational parameters of 6DOF yaw, pitch, and roll in one-thousandth of a degree. A final representation of the data is shown in Figure 4.2. Shakedown runs were performed to establish a procedure that would be safe and viable for the human test subjects.



Date	Time	X	Y	Z	Yaw	Pitch	Roll
11/9/2012	15:56:27.66	0	0	0	0	0	0
11/9/2012	15:56:27.88	-1.996	1.132	-17.898	0.366	0.393	-0.286
11/9/2012	15:56:28.06	-1.539	0.513	-3.515	0.482	-0.134	-0.364
11/9/2012	15:56:28.28	-1.452	0.729	-1.776	0.34	-0.208	-0.217
11/9/2012	15:56:28.47	-1.86	1.039	-6.193	0.171	0.376	0.144
11/9/2012	15:56:28.69	-4.394	2.937	-21.381	-0.128	0.371	0.126
11/9/2012	15:56:28.87	-3.796	2.934	-23.058	0.59	0.699	0.127
11/9/2012	15:56:29.09	-3.012	4.211	-32.01	0.369	0.641	0.199
11/9/2012	15:56:29.28	-1.711	2.561	-19.056	0.625	0.542	-0.104
11/9/2012	15:56:29.50	-0.401	1.076	-1.833	0.57	0.604	-0.52
11/9/2012	15:56:29.68	-0.861	2.707	-17.454	1.027	0.539	-0.426
11/9/2012	15:56:29.90	0.334	1.978	-11.972	0.659	1.164	0.095
11/9/2012	15:56:30.09	-1.509	4.22	-22.624	0.602	1.592	0.581
11/9/2012	15:56:30.31	-0.063	4.314	-19.369	1.051	1.548	0.537
11/9/2012	15:56:30.50	1.975	3.844	-19.288	0.921	1.694	0.895
11/9/2012	15:56:30.71	7.155	1.887	-1.676	0.413	1.609	0.76
11/9/2012	15:56:30.90	4.425	3.115	-13.86	0.91	2.298	1.133
11/9/2012	15:56:31.12	5.961	0.974	0.683	0.589	2.062	0.692
11/9/2012	15:56:31.31	3.88	1.513	-4.362	0.322	1.882	0.756
11/9/2012	15:56:31.52	4.329	1.677	-8.517	0.566	1.953	0.5
11/9/2012	15:56:31.71	3.602	1.723	-10.885	0.644	2.036	0.361
11/9/2012	15:56:31.93	4.207	0.478	0.497	0.829	2.091	0.026
11/9/2012	15:56:32.12	2.486	1.197	-4.792	0.8	2.303	-0.381
11/9/2012	15:56:32.34	1.105	0.757	-3.975	0.868	2.418	-0.506

Figure 4.2: Sample of the Data

Chapter 5

Results and Discussion

The data for thirteen test subjects was collected and tabulated using Microsoft Excel 2010. A Butterworth filter, see Appendix D, was used to remove noise from the data and two-dimensional plots were constructed for analysis. Ten of the test subjects flew all three sessions, one subject flew two sessions, and two subjects flew one session. Because of completeness, only the data of the ten subjects who flew all three sessions was analyzed. Based on the observations of the test examiner, the author of this paper, the final sequence of landings were evaluated for fatigue by looking at the y and pitch motions of the head, while the four 360 degree ascending and descending turns were evaluated for head tilt by looking at the yaw and roll motions of the head. Because of the small population of subjects, the other degree-of-freedom head motions could not be determined relevant to fatigue or head tilt.

5.1 Fatigue

The most obvious place to search for evidence of fatigue in the data was in the sequence of landings at the end of the Master Set of maneuvers. During the landings, the test observer noted the test subjects changing their posture in the flight chair, which resulted in a change in the y and pitch motions of the head, see Figure 5.1. The test observer interpreted these shifts as visual signs of fatigue. There were two different scenarios of shifts noted by the test observer that were evenly distributed among the test subjects. The first scenario included a vertical upright shift with high frequency pitching oscillations of the head, while the second scenario included a downward shift of the head accompanied by fewer pitching oscillations.

To study the data obtained by the TrackIR4 for these two scenarios, the y and pitch degrees-of-freedom were plotted.

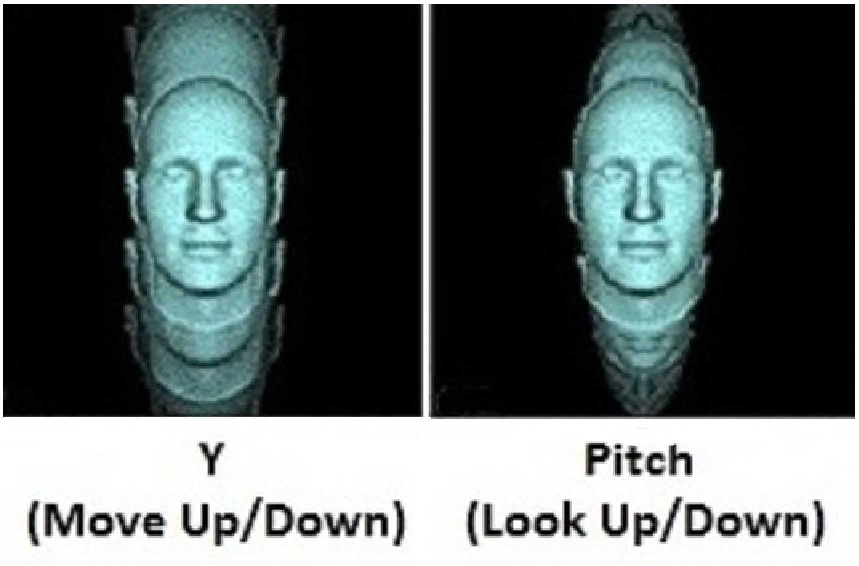


Figure 5.1: Y and Pitch Degrees of Freedom[8]

In Figures 5.2 - 5.5, the y and pitch degrees-of-freedom for the first and final complete standard landing patterns of a test subject, denoted as Subject 1, are plotted for the final two sessions, respectively, as a representation of the first scenario. As Subject 1 settled into flying the landing pattern, he began to recline in the flight chair. As a result, his head moved down, which is represented by the decrease in the y motion of the head. Also during this time, a high frequency oscillation in the pitching motion of the head is occurring, and is associated with the subject continually glancing from the simulation view to the instrument panel in order to keep the aircraft on course. Finally, as Subject 1 begins his turn from base leg to final approach, he begins to straighten back up in the flight chair, which correlates with an increase in the y motion of the head as he readies himself for landing the aircraft.

In Figures 5.6 - 5.9, the y and pitch degrees-of-freedom for the first and final complete standard landing patterns of a test subject, denoted as Subject 2, are plotted for the final two sessions, respectively, as a representation of the second scenario. As Subject 2 settles into flying the landing pattern, he begins to lean toward the computer screen. As a result,

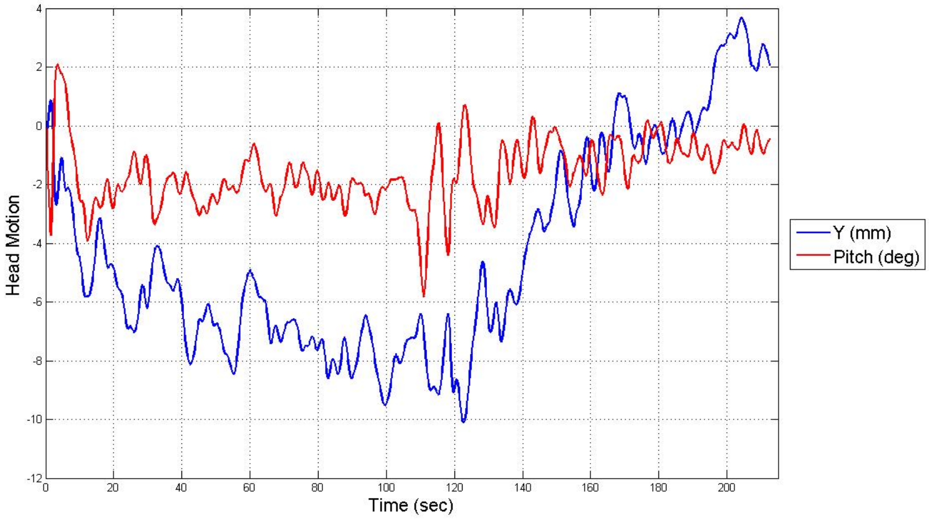


Figure 5.2: Flight Session 2, First Complete Standard Landing Pattern for Subject 1

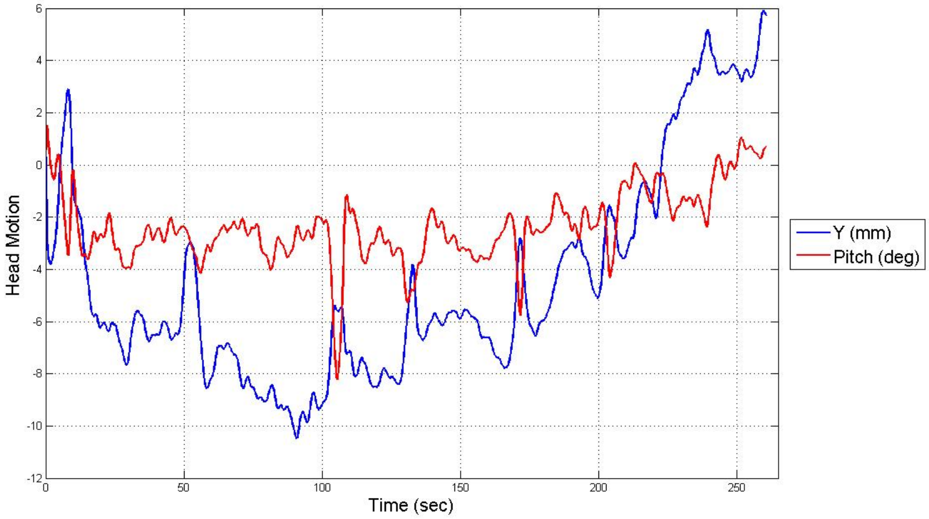


Figure 5.3: Flight Session 2, Final Complete Standard Landing Pattern for Subject 1

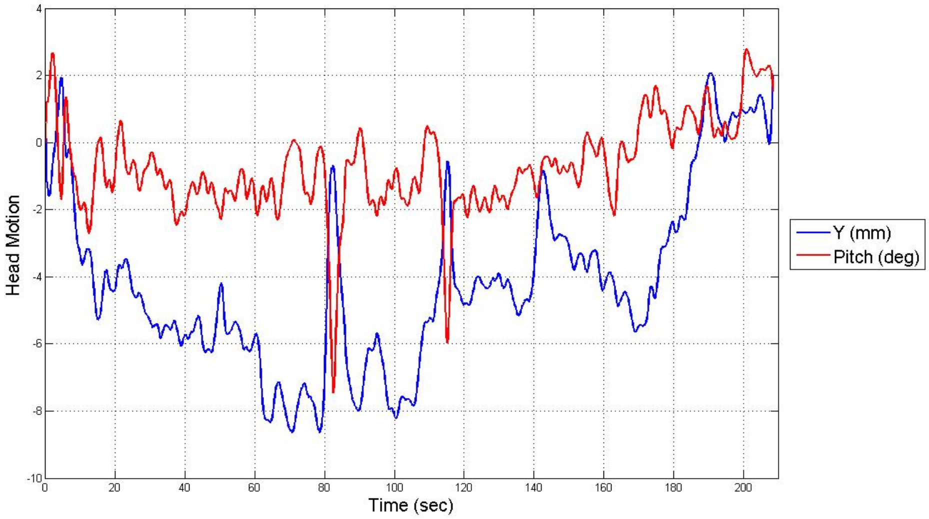


Figure 5.4: Flight Session 3, First Complete Standard Landing Pattern for Subject 1

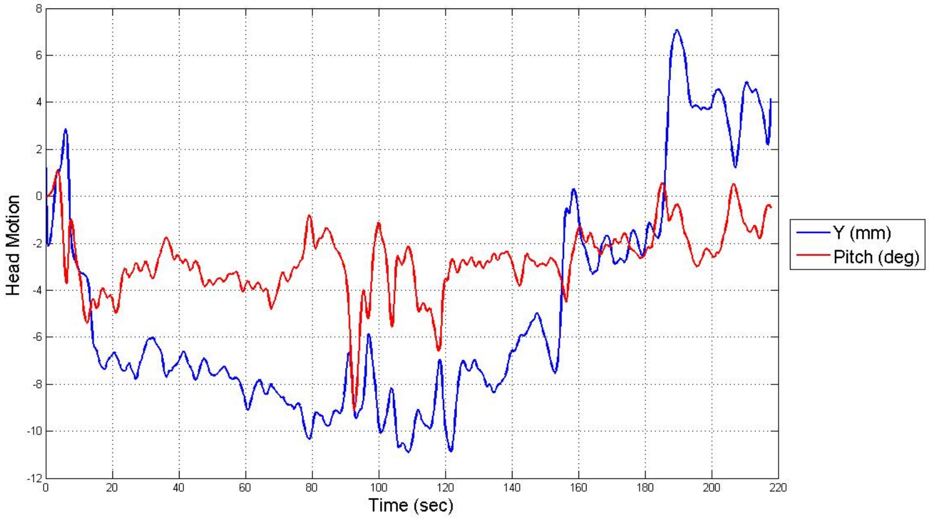


Figure 5.5: Flight Session 3, Final Complete Standard Landing Pattern for Subject 1

his head moves down, which is represented by the decrease in the y motion of the head. The pitching motion of the head is less frequent than seen in scenario one, because Subject 2 is moving his head up and down to look between the the simulation screen and the instrument panel, which is represented by the higher amplitude y motion.

5.2 Head Tilt

After observing a tilting of the head during the four 360 degree ascending and descending turns, analysis of these maneuvers revealed head tilt results similar to Zallen *et al.*[7], and provide additional evidence that yawing and rolling motions of the head are indicators of head tilt, see Figure 5.10. In Figures 5.11 - 5.13, the yaw and roll degrees-of-freedom for the 360 degree ascending and descending turns of all three sessions of a subject, noted as Subject 3, are depicted, respectively. An interesting observation is that the yaw and roll motion become more pronounced during portions of the two descending turns than in the two ascending turns. This correlates with the higher degree of difficulty when flying a descending turn.

Another interesting observation is the symmetry between yaw and roll. The TrackIR Capture Program measures yaw to the right and the left as positive and negative angles, respectively, while roll is measured to the right and left as negative and positive angles, respectively. This coupling is similar to the motion of an aircraft as described by the subject of flight dynamics. In the lateral dynamics of an airplane, a roll rotation produces both a yawing and rolling moment while subsequently a yaw displacement produces a yawing and rolling moment[47]. These observations are consistent as shown in Figures 5.14 - 5.16 that depict the head motion of another test subject, denoted as Subject 4.

5.3 Anecdotal Comment

There were two distinct groups of test subjects as described earlier, younger/lesser experienced pilots and older/more experienced pilots. The older test subjects had more

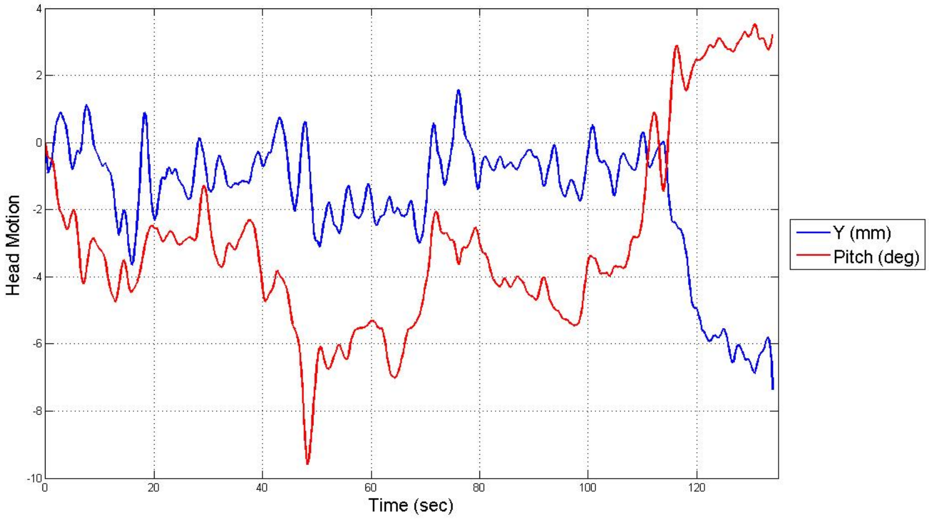


Figure 5.6: Flight Session 2, First Complete Standard Landing Pattern for Subject 2

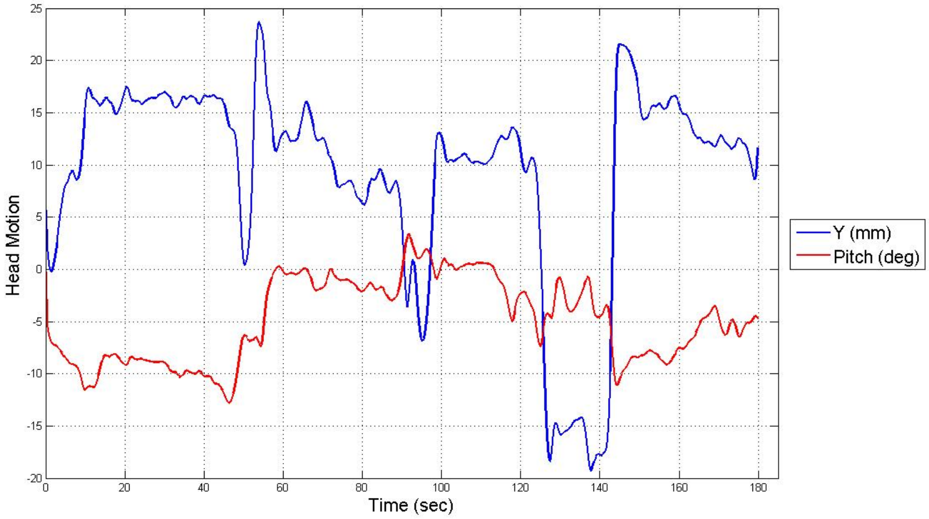


Figure 5.7: Flight Session 2, Final Complete Standard Landing Pattern for Subject 2

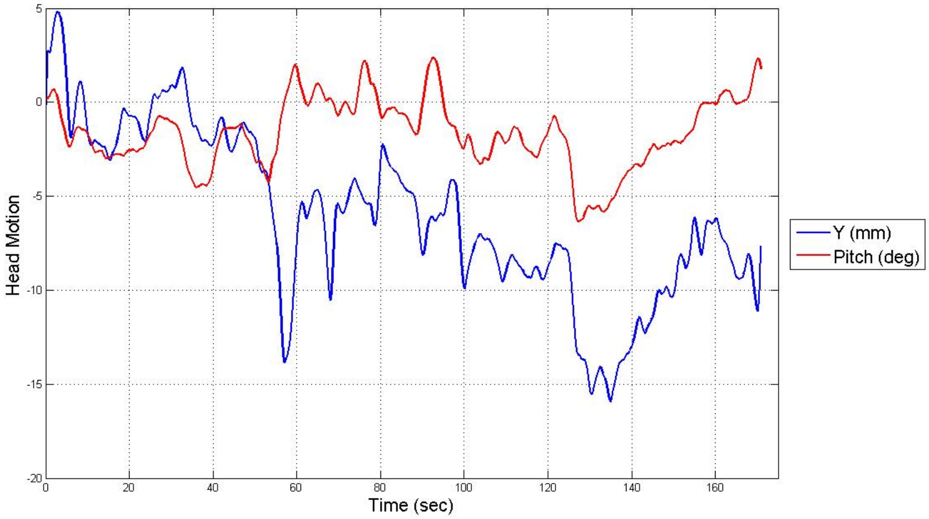


Figure 5.8: Flight Session 3, First Complete Standard Landing Pattern for Subject 2

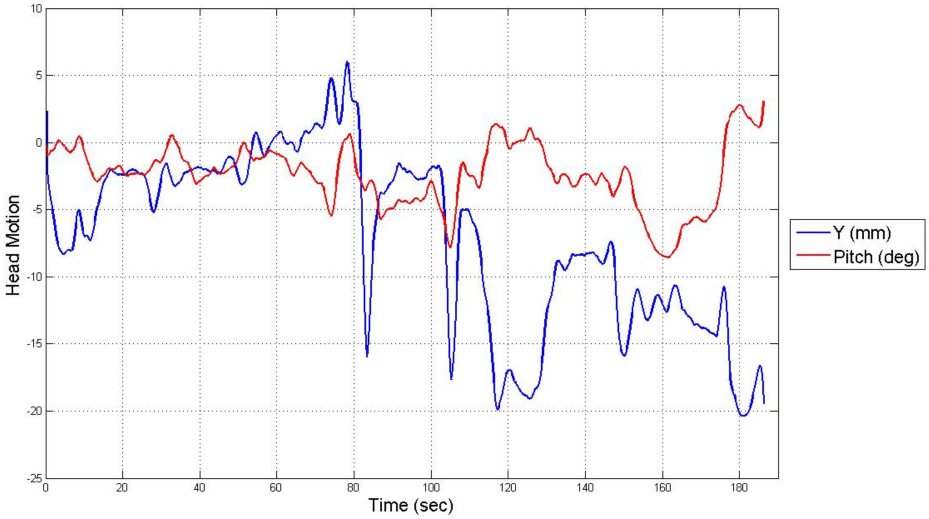


Figure 5.9: Flight Session 3, Final Complete Standard Landing Pattern for Subject 2

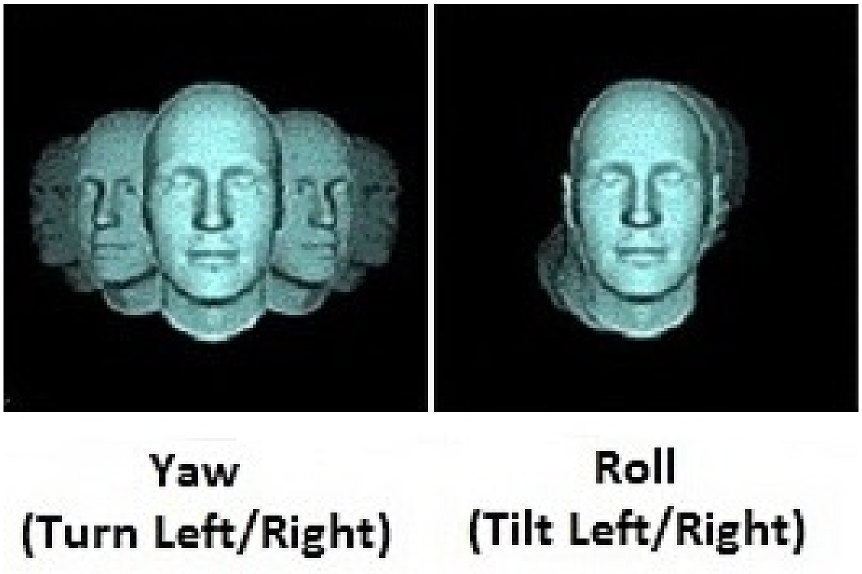


Figure 5.10: Yaw and Roll Degrees of Freedom[8]

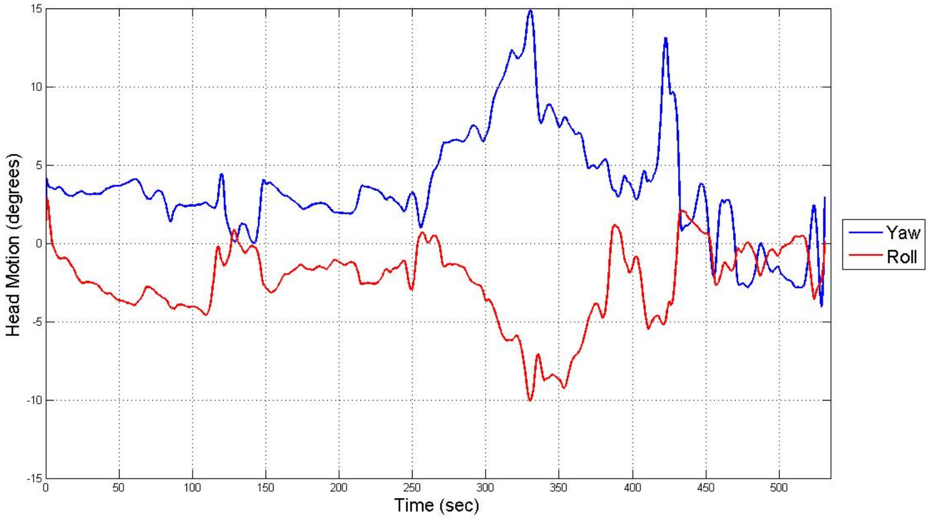


Figure 5.11: Flight Session 1, Maneuvers for Subject 3

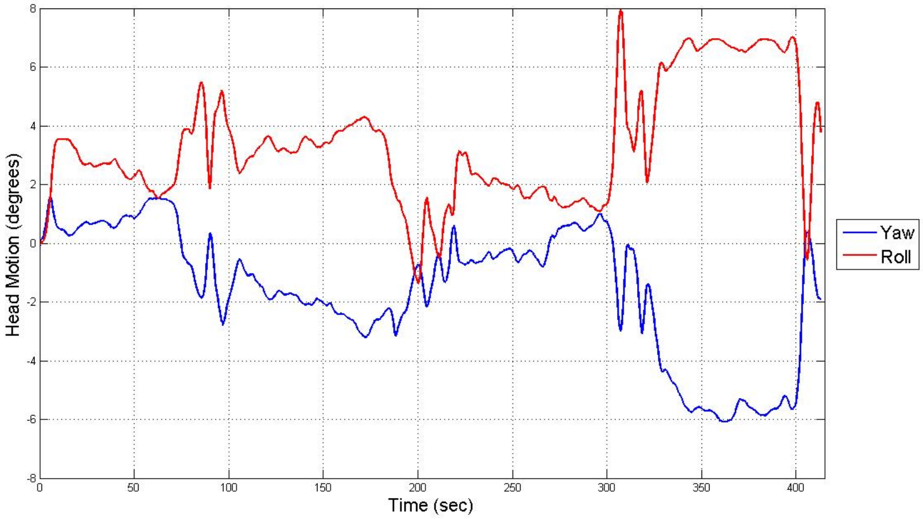


Figure 5.12: Flight Session 2, Maneuvers for Subject 3

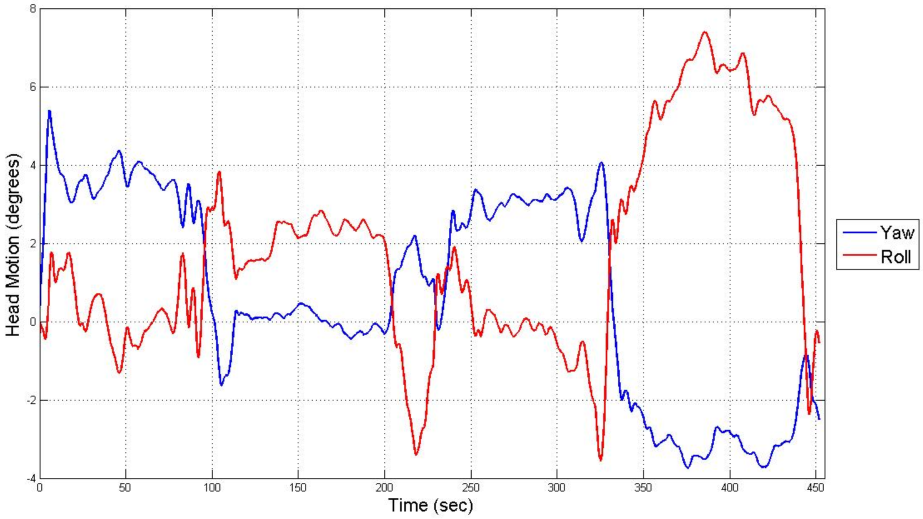


Figure 5.13: Flight Session 3, Maneuvers for Subject 3

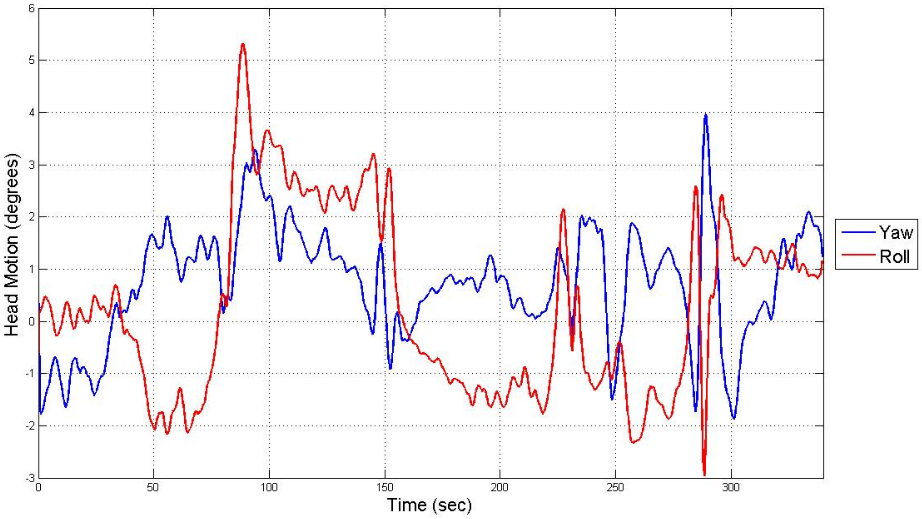


Figure 5.14: Flight Session 1, Maneuvers for Subject 4

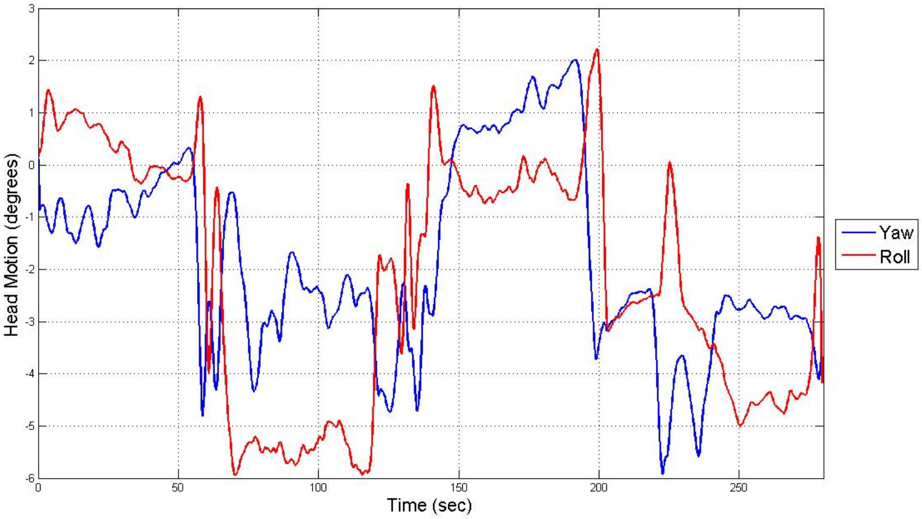


Figure 5.15: Flight Session 2, Maneuvers for Subject 4

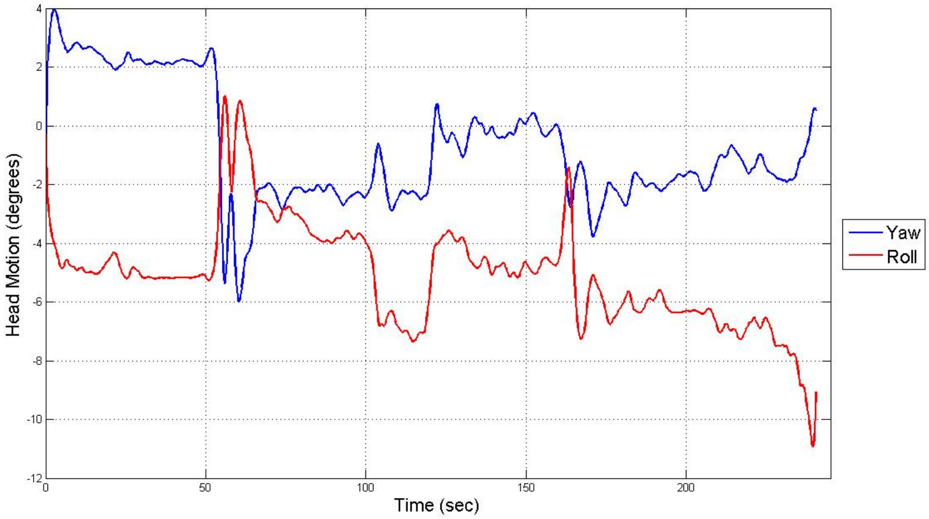


Figure 5.16: Flight Session 3, Maneuvers for Subject 4

trouble adjusting to the flight simulator than the younger test subjects even though they had an average of more than 5000 hours and 40 years of experience compared to the younger test subjects. This can be attributed to the familiarity the younger test subjects have with simulators compared to the older test subjects. The patterns indicating fatigue and head tilt described above which represent flights of the younger test subjects also represent the patterns of the older test subjects. The difference can be seen in the increased frequency of motion exhibited that corresponds with the uncertainty visibly shown and expressed by the older test subjects. Figures 5.17 - 5.19, denoted as flown by Subject 5, are representative of an older test subject's maneuvers and landings, respectively.

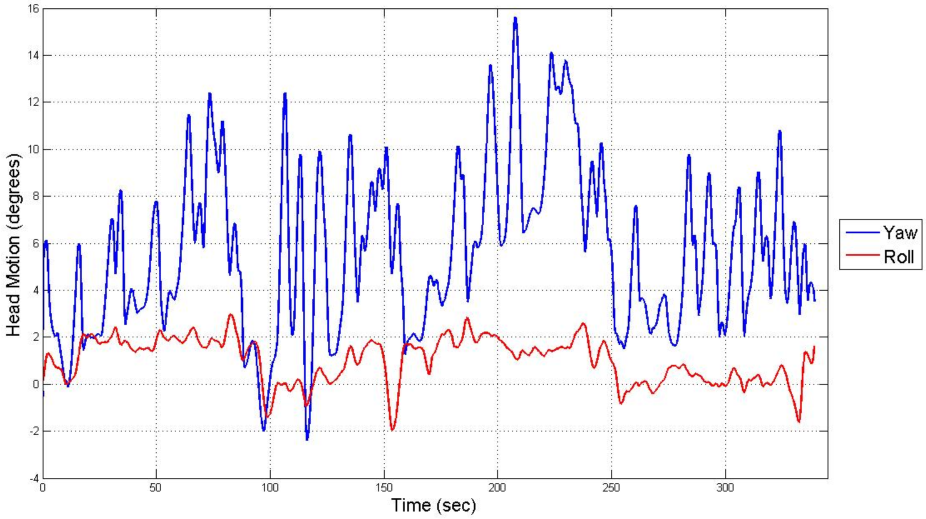


Figure 5.17: Flight Session 1, Maneuvers for Subject 5

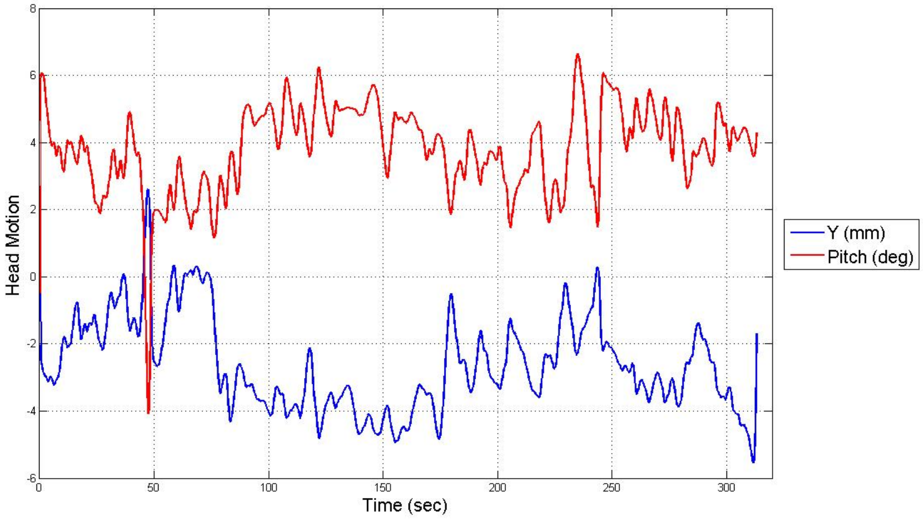


Figure 5.18: Flight Session 2, First Complete Standard Landing Pattern for Subject 5

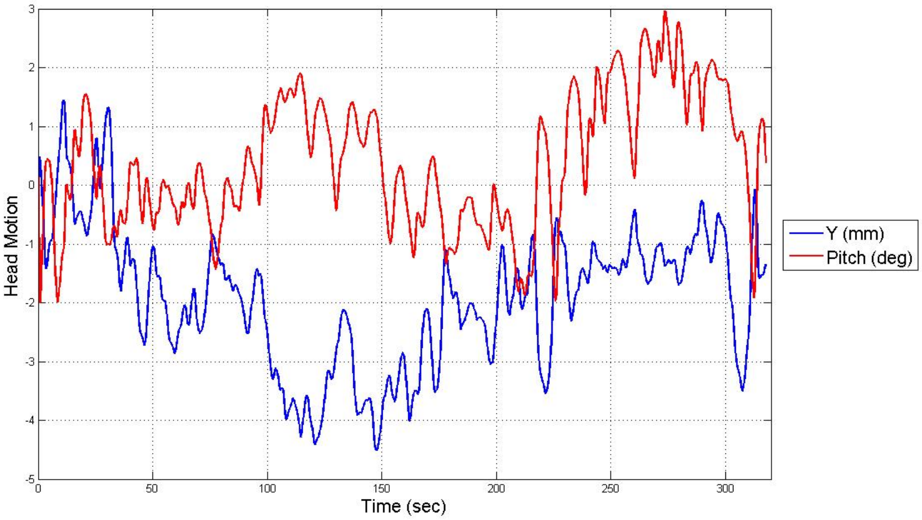


Figure 5.19: Flight Session 2, Final Complete Standard Landing Pattern for Subject 5

Chapter 6

Conclusions and Recommendations

The limited data generated during this study indicate that fatigue is evidenced by the y and pitching motions of the head, while head tilt is evidenced by a coupled yawing and rolling motion of the head. Although the remaining degrees-of-freedom for each human factor were analyzed, no correlation with the test observations could be drawn. Also, as a result of the small population of subjects, a statistical correlation could not be performed to determine if the additional degrees-of-freedom indicated either fatigue or head tilt.

There is strong evidence that the y motion of the head is a good indicator of fatigue. This agrees with the research done by Zallen, *et al.* Additional observation suggests that pitch is also a motion of the head that indicates fatigue. Certainly, there is more to be determined. It is recommended that additional research be done on y and pitch to determine subtle differences with a statistical number of test subjects. For head tilt, this research supports conclusions similar to Previc's research in the 1990s[37] that head tilt is associated with a lateral rolling motion of the head. It also supports the conclusion similar to those based on the research done by Zallen, *et al.*[7], that head tilt can be indicated by not just a lateral rolling motion of the head but also by a three-dimensional yawing motion of the head, with the addition that yaw and roll are coupled.

In order to determine definite indicators of fatigue and head tilt, a statistical number of test subjects, no less than 30 recommended for results with a statistical error margin less than 10 percent, need to be evaluated in order to perform correlation statistics between the 6DOF. The sessions need to last a sufficient length of time so that there is no doubt the test subjects are exhibiting fatigue at the end of the session so subsequent analysis can determine indicators. By also utilizing the motion of the aircraft in conjunction with the subject's head motion, a fourier analysis can be used to determine the difference in the subject's motion relative to the motion of the aircraft and the subject's motion relative to the physical effects on the body. Finally, instead of looking at the subject's head motion over time from take-off to landing, analysis of the head motion from landing back through the landing pattern in terms of distance flown could provide a specific location in the pattern where head anomalies more frequently occur. This area of interest can be isolated in order to look more specifically at the human factors associated with UAV crashes occurring at landing.

It is the author's conclusion that every pilot will have a unique pattern of head motion for aircraft maneuvers flown in a simulator-like environment. As a result, the methods used in this study are recommended as a basis for current application to the monitoring of pilot head motion during flight in a simulator-like environment. The pilot's specific pattern of head motion can then serve as a baseline to evaluate the pilot's head motion in real time during missions. If anomalies are present, replacing the pilot with a fresher backup pilot can help avert potential accidents. The pilot can then be evaluated to determine the cause of the anomaly and preventive measures can be taken to reduce the risk of a reoccurrence.

6.1 Further Areas of Study

Note in Figures 5.11 and 5.13 how the first maneuver, an ascending turn to the right for 360 degrees, corresponds with a yawing motion to the right and rolling motion to the left. However in Figure 5.12, the first maneuver corresponds with a yawing motion to the left and rolling motion to the right. This variation in the direction of Subject 3's head motion during the same maneuver is a conundrum that warrants further study. A similar scenario can be seen in Figures 5.14 - 5.16 with Subject 4.

Another observation includes the effect of enabling the crash option in Microsoft Flight Simulator X. Although as a result of this only one test subject crashed and the simulation had to be restarted, the angle of approach when landing was observed by the test examiner to be the main cause of the crash. This was also similar to the cases when test subjects did not crash but had hard landings that caused the aircraft to “bounce” down the runway until they could regain control. This is believed to be an effect of the loss of control discussed in Section 2.2.2 and is recommended for future study as another reason for multiple crashes during landing of UAVs.

6.2 Modifications to Instrumentation

Two modifications to the MGI Flight Simulator are recommended before further study is conducted. During the simulation sessions, some shifts, resulting from fatigue, were so dramatic that the flight chair was pushed away from the simulator. Also, the majority of the test subjects noted that they would have liked to move the chair closer to or further away from the simulator in order to make it easier to reach the pedals, which would better accommodate their specific height during the sessions. In order to prevent these dramatic shifts and increase the ergonomics of the design, the floor of the simulator could be built out where the seat can be bolted to a track that allows the seat to be adjusted forward or backward to account for the varying heights of the test subjects. Also, the majority of test subjects noted that the instrument panel for the Predator UAV simulation differs significantly from a standard aircraft instrument panel. This required a higher degree of attention from the test subject on the instrument panel during the simulation than normally would have been required if the simulation instrument panel had been formatted like a standard aircraft instrument panel. Therefore, it is recommended that the Predator instrument panel be modified to resemble that of a standard aircraft instrument panel.

Bibliography

[1] Salvendy, G., *Handbook of Human Factors and Ergnomics*, John Wiley & Sons Inc., Section 61, 2012, 4th Ed.

[2] Drone Crash Database, Drone Wars UK, http://dronewarsuk.wordpress.com/drone-crash-database/, January 2, 2013.

[3] Salazar, G.J., "Fatigue in Aviation," FAA Civil Aerospace Medical Institute, Publication OK-07-193, Oklahoma City, Oklahoma, USA.

[4] Etheridge, T., Personal Communication, Florida Institue for Machine and Human Cognition, Pensacola, FL, USA, December 2011.

[5] Torticollis, A.D.A.M. Medical Encyclopedia, http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001757/, December 19, 2012.

[6] Pettorossi, V.E., *et al.*, "Head Position Modulates Optokinetic Nystagmus," *Experimental Brain Research*, Volume 213, Issue 1, 2011.

[7] Zallen, H., Cochran, J.E., and Bailey, J.A., "Head-Tilt and Pilot Fatigue Measured by Flight Simulation," *Aircraft Engineering and Aerospace Technology: An International Journal*, Volume 84, Issue 1, 2012.

[8] Natural Point, Inc., TrackIR4 and TrackClip, Corvallis, Oregon, USA, 2013.

[9] Wiegmann, D.A., and Shappell, S.A., *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*, Ashgate Publishing Company, Chapter 1, 2003.

[10] Federal Aviation Administration, "Flight Member Duty and Rest Requirements," November 18, 2011.

[11] Caldwell, J.A., "The Impact of Fatigue in Air Medical and Other Types of Operations: A Review of Fatigue Facts and Potential Countermeasures," *Air Medical Journal*, Volume 20:1, October 2000.

[12] Rosekind, M.R., *et al.*, "Pilot Fatigue, Sleep, and Circadian Rhythms: NASA Fatigue Countermeasures Program," *FAA Aviation Safety Journal*, pgs. 20-25, 1993.

[13] Van Dongen, H.P., Dinges, D.F., "Circadian Rhythms in Fatigue, Alertness, and Performance," *Principles and Practice of Sleep Medicine*, Saunders, pgs. 391-399, 2000.

[14] Frakes, M.A., *et al.*, "Sleep Debt and Outside Employment Patterns in Helicopter Air Medical Staff Working 24-Hour Shifts," *Air Medical Journal*, Volume 26:1, January-February 2007.

[15] David, M.C., *et al.*, "Fatigue in Airline Pilots After an Additional Days Layover Period," *Aviation, Space, and Environmental Medicine*, Volume 81, Number 11, November 2010.

[16] Strauss, S., "Pilot Fatigue," www.pilotfriend.com/aeromed/medical/fatigue1.htm, February 18, 2013.

[17] Lal, S.K.L. and Craig, A., "Electroencephalography Activity Associated with Driver Fatigue: Implications for a Fatigue Countermeasure Device," *Journal of Psychophysiology*, Volume 15, Number 3, 2001.

[18] Zhang, Z. and Zhang, J., "Driver Fatigue Detection Based Intelligent Vehicle Control," The 18th International Conference on Pattern Recognition, 2006, Hong Kong.

[19] Albu, A.B., *et al.*, "A Computer Vision-Based System for Real-Time Detection of Sleep Onset in Fatigued Drivers," 2008 IEEE Intelligent Vehicles Symposium, Eindhoven University of Technology, Eindhoven, The Netherlands.

[20] Noor, H.A.M. and Ibrahim, R., "Image Processing Using Eyelid Blinking And Mouth Yawning to Measure Humans Fatigue Level," Third Asia International Conference on Modelling and Simulation, 2009, Bandung, Bali, Indonesia.

[21] Wang, Q., *et al.*, "Driver Fatigue Detection: A Survey," Proceedings of the 6th World Congress on Intelligent Control and Automation, 2006, Dalian, China.

[22] Coetzer, R.C. and Hancke, G.P., "Driver Fatigue Detection: A Survey," IEEE Africon 2009, Nairobi, Kenya.

[23] Xie, X., Sudhakar, R., and Zhuang, H., "A Cascaded Scheme for Eye Tracking and Head Movement Compensation," IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans, Volume 28, Number 4, July 1998.

[24] Smith, P., *et al.*, "Monitoring Head/Eye Motion for Driver Alertness with One Camera," 15th International Conference on Pattern Recognition, Volume 4, pgs. 636-642, 2000, Los Alamitos, California, US.

[25] Ji, Q., Zhu, Z., and Lan, P., "Real-Time Nonintrusive Monitoring and Prediction of Driver Fatigue," *IEEE Transactions on Vehicular Technology*, Volume 53, Number 4, July 2004.

[26] Anders, G., "Pilot's Attention Allocation During Aproach and Landing Eye- and Head-Tracking Research in an A330 Full Flight Simulator," Institute for Aeronautics and Astronautics, Technische Universitat, Berlin, Germany.

[27] General Atomics Predator, http:spyflight.co.uk/Predator.htm, January 12, 2013.

[28] Unmanned Aerial Vehicles (UAV): Predator, Air Force HSI, http://www.wpafb.af.mil/shared/media/document/AFD-090121-039.pdf, November 17, 2012.

[29] US Air Force FY 2011 Budget Estimates, US Air Force Aircraft Procurement, http://www.saffm.hq.af.mil/shared/media/document/AFD-100128-072.pdf, February 22, 2013.

[30] MQ-1B Fact Sheet, Air Combat Command, Public Affairs Office, Langley Air Force Base, Virginia, USA, 2012.

[31] General Atomics and Affiliated Companies, http://www.ga.com/image-library/unmanned-aircraft-systems, March 22, 2013.

[32] Spravka, J.J., Moisio, D.A., and Payton, M.G., "Unmanned Air Vehicles: A New Age in Human Factors Evaluations," No. AFFTC-PA-05069. Air Force Flight Test Center, Edwards Air Force Base, California, 2003.

[33] Williams, K. W., "A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications," No. DOT/FAA/AM-04/24, Federal Aviation Administration, Civil Aeromedical Institute, 2004.

[34] Cooke, N.J., *et al.*, *Advances in Human Performance and Cognitive Engineering Research, Volume 7: Human Factors of Remotely Operated Vehicles*, Elsevier Ltd., Chapter 2, 2006, 1st Ed.

[35] American Optometric Association, Computer Vision Syndrome (CVS), http://www.aoa.org/x5374.xml, February 15, 2013.

[36] Greenberg, G., "Eye-Dominance and Head Tilt," *American Journal of Psychology*, Volume 73, pgs. 149-151, 1960.

[37] Previc, F.H., "The Relationship Between Eye Dominance and Head Tilt in Humans," *Neuropsychologia*, Issue 32, pgs. 1297-1303, 1994.

[38] Putnam, S., *et al.*, "Direction and Rliability of Head Tilt in Humans," *Laterality*, Volume 1, Issue 2, pgs. 153-160, 1996.

[39] CH Products, LLC., CH Flight Simulator Yoke and Precision CH Pedals, Vista, California, USA, 2010.

[40] Matrox Graphics Inc., Matrox TripleHead2Go, Dorval, Quebec, Canada, 2012.

[41] First Class Simulations, UAV Predator, Banbury, Oxforshire, UK, 2008.

[42] Zallen, H., Embedded TrackIR Capture System, Malone Group International, Auburn, AL, USA, December 2007.

[43] Kay, M., Certified U.S. Federal Aviation Administration Flight Instructor, unpublished communication, 2012.

[44] Harbor Freight Tools, Cen-Tech Self-Leveling Laser Level, Calabasas, California, USA, 2012.

[45] Howe, A., and Slaughter, S., *A Fun Way to Enjoy FSX: Tips, Tricks, and Trips*, Abacus, pgs. 187-202, 2007.

[46] Arctic Tern Equipment, http://www.interstateaircraft.com/Equipment.html, February 27, 2013.

[47] Etkin, B. and Reid, L.D, *Dynamics of Flight: Stability and Control*, John Wiley & Sons Inc., Chapter 3.8, 1996, 3rd Ed.

[48] AU Institutional Review Board for the Protection of Human Subjects in Research, http://www.auburn.edu/research/vpr/ohs/, March 2, 2012.

[49] Air Force World, http://airforceworld.com/heli/eng/predator.htm, February 27, 2013.

[50] UAV Predator / Repear Target Destruction Ground Control Station Operations, http://www.frequency.com/video/uav-predator-reaper-target-destruction/3851824/-/5-1226454, February 26, 2012.

[51] NaturalPoint, OptiTrack API, Version: 1.82, For SDK Version: 1.1.035, Date 07/25/2008.

[52] Butterworth, S., "On the Theory of Filter Amplifiers," *Wireless Engineer*, Volume 7, pgs. 536-541, 1930.

[53] Cochran, J.E., Department Head of Aerospace Engineering at Auburn University, personal communication, February 25, 2013.

Appendix A

Institutional Review Board Protocol, 12-082 EP1203

In order to do research involving human testing, an Institutional Review Board (IRB) Protocol must be obtained. The IRB insures that the rights and welfare of human test subjects are not violated by reviewing all research activities that involve human test subjects for compliance with all applicable federal, state, local, and institutional regulations, guidelines, and ethical research principles[48]. The Auburn University IRB Protocol, 12-082 EP1203, for this study was approved on March 3, 2011 to allow human testing as described in Chapter 4. Test subjects were recruited from the student population of Auburn University and from the general population in the surrounding area with the requirement that the test subject have a Federal Aviation Administration Private Pilot Certificate. The IRB approved flyer and handout used for recruitment are shown in Figures A.1 and A.2

The Auburn University Institutional Review Board has approved this document for use from
3/26/12 to 3/25/13
Protocol # 12-082 EP 1203

RESEARCH PARTICIPANTS NEEDED

Are you an FAA Certified Pilot age 19 or up?

Be part of a research study conducted by the
Department of Aerospace Engineering

Are You Interested In Flight Simulation??

Are you interested in Unmanned Aerial Vehicles (UAVs)??

- Purpose of this study is to learn more about the relationship between simulation flight and the fatigue experienced
- Benefits include the opportunity to fly a simulation of the Predator on a static flight simulator

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Figure A.1: IRB Stamped Flyer Approved for Recruitment

UAV Pilot Fatigue Measured by Flight Simulation

NEED STUDENT FAA CERTIFIED PILOTS TO VOLUNTEER TO FLY PREDATOR SIMULATION

Due to the increase of recent crashes during landing of UAVs that have been deemed pilot error, a method has been proposed for detecting fatigue of the operator. The method includes using tracking software to track the 6 degrees of freedom of the head of a test subject while they fly a Predator software simulation on a flight simulator. The analysis of the data and subsequent results will be the core focus of an Aerospace Engineering Master's thesis.

Shown in the picture to the left is the flight simulator. It includes a triple monitor set up to give peripheral vision of the simulation while in flight and comes with precision pedals and yoke controls.

Time commitment would include 4 sessions; the first would be to get comfortable with the simulator while the final three would be viewing and then flying the simulation while being measured by tracking software. This requires wearing a baseball cap with a clip on the brim as shown in the picture below.

No private information will be asked for, the only thing needed is your name and to see your pilots license before you start the first session.

Hopefully this research will benefit you in the future as pilots to help prevent pilot error in not only UAVs but any aircraft.

Those interested in participating please contact Judith Bailey, baileju@tigermail.auburn.edu

The Auburn University Institutional
Review Board has approved this
document for use from
3/26/12 to 3/25/13
Protocol # 12-082 EP 1203

Figure A.2: IRB Stamped Handout Approved for Recruitment

Appendix B

Flight Simulator Ensemble

B.1 MGI Fixed-Base Flight Simulator

The MGI Fixed-Base Flight Simulator was designed by Malone Group International's Dr. Harold Zallen, President and CEO, in January 2008. The MGI Fixed-Base Flight Simulator was fabricated at Baird Corp by James J. Baird, Jr., Architect and CEO, and Dr. Harold Zallen. It was completed December 2008 and has been effectively used for research. In November 2011, the MGI Fixed-Base Flight Simulator was donated to the Auburn University Samuel Ginn College of Engineering Department of Aerospace Engineering by Malone Group International for permanent retention by the Department of Aerospace Engineering.

The MGI Fixed-Base Flight Simulator was designed to be similar to the original General Atomics MQ-1 and RQ-1 Predator UAV ground control station at Creech Air Force Base, Ironstone, Nevada, USA. Subsequent to the design of the MGI Fixed Base Flight Simulator, the USAF changed from a one operator setup, see Figure B.1, to a three-member team with separate LCD screen, a view of two of the members is shown in Figure B.2. The three-member crew for the Predator consists of a pilot to control the aircraft, an enlisted aircrew member to operate sensors and weapons, and a mission coordinator who assumes the role of navigator[30].

B.2 Embedded TrackIR Capture System

The Embedded TrackIR Capture System is a composite of programs that converts the test subject's head motion into a text file that can be analyzed with various programs[42].

Figure B.1: Original Predator Ground Control Station[49]

Figure B.2: Revised Predator Ground Control Station[50]

It includes the TrackIR Software, Optitrack API Software, and two subprograms, trackirwin32dll.dll and ocx.exe, that allow the TrackIR Capture Program to operate. The TrackIR Software, NaturalPoint Version 4.1.030.Final, allows the TrackIR4 to communicate with the computer. The OptiTrack API Software[51] converts the analog signals of the TrackIR Software to digital data. The trackirwin32dll.dll is a dynamic link library file that is directly embedded into the Microsoft Operating System. It works with the ocx.exe file to link with the Optitrack API Software and produce a text file of the data for analysis.

Appendix C

Modification of Predator Simulation Instrument Panel

The instrument panel of the Predator UAV simulation was originally very small and located at the bottom of the right most screen in the three monitor setup, shown in Figure C.1. In order to make it easier for viewing, the panel code for the Predator was modified[45]. The steps used to modify the panel code are as following:

1. Make sure Microsoft Flight Simulator X is shut down.
2. Place the mouse over the Microsoft Flight Simulator X icon, right click, and select the Properties option.
3. Click the Find Target button on the General Tab.
4. Double-click the SimObject folder, then the Airplane folder, the FCS_MQ-1_Predator_UAV folder, and finally the Panel folder.
5. Right-click the panel.cfg file and select the Open option.
6. Open the file using the program Notepad.
7. Scroll down in the document to the section in brackets denoted [window00].
8. Modify the line in the code that starts with gauge00 by replacing the string of numbers, "553,482,302,198," with the string of numbers, "325,400,450,375."
9. Modify the line in the code that starts with gauge01 by replacing the string of number, "172,482,302,198," with the string of numbers, "0,482,302,198."
10. Save the file and close all folders.

11. Start Microsoft Flight Simulator X and visually confirm that the change has been made to the panel, see Figure C.2.

The first two numbers in the string of code denote the starting position of the upper-left most corner of the instrument panel. By changing the first two numbers of gauge00 from “553,482” to “325,400,” the panel now begins 325 pixels to the right and 400 pixels down from the upper-left corner of the screen opposed to its previous location of 553 pixels to the right and 482 down from the upper-left corner of the screen. The final two numbers denote the size of the panel. The panel denoted gauge00 starts off 302 pixels wide and 198 pixels tall, but it is enlarged to 450 pixels wide and 375 pixels tall. This change resulted in easier viewing of the instrument panel for all test subjects.

Figure C.1: Original Predator Simulation Instrument Panel

TIME
16:56990

DATE
10:35390

POSITION
N 32 °36.36'
W 085 °26.18'

AIRSPEED 0 kts	AOA 0.0	HEADING 5	PITCH -2°	OAT 13°C
ALTITUDE 782 ft	VERTICAL SPEED 0 m/s	ACCELERATION 1 m/s	BANK 0°	EGT -273°C

Figure C.2: Modified Predator Simulation Instrument Panel

Appendix D

Butterworth Filter Code

A Butterworth filter is a signal processing filter that removes certain frequencies of data in order to reduce interfering signals and background noise resulting in analysis of purer data[52]. After collecting and tabulating the 6DOF data in Microsoft Excel, a butterworth filter was used in Matlab Version R2010a to clear the data of noise so that the underlying patterns associated with fatigue and head tilt could be easily viewed. A copy of the Butterworth filter code used[53] can be seen below.

```
function    Y = butterworth(X,T,WC0,NP)
Y(1,1) = X(1,1);
Y(2,1) = X(2,1);
Y(NP,1) = X(NP,1);
Y(NP - 1,1) = X(NP - 1,1);
CFC = WC0;
wd = 2.*pi*CFC*2.0775;
wa = sin(wd*T/2)/cos(wd*T/2);
denom = 1.  + sqrt(2.)*wa + wa^2;
a0 = wa^2/denom;
a1 = 2.*a0;
a2 = a0;
b1 = -2.*(wa^2 - 1)/denom;
b2 = (-1. + sqrt(2)*wa  - wa^2)/denom;
for I = 3:1:NP-2
    Y(I,1) = a0*X(I,1)  + a1*X(I - 1,1) + a2*X(I - 2,1) + b1*Y(
       I - 1,1) + b2*Y(I - 2,1);
end
for J = NP - 2:-1:3
    Y(J,1) = a0*X(J,1)  + a1*X(J + 1,1) + a2*X(J + 2,1) + b1*Y(
       J + 1,1) + b2*Y(J + 2,1);
end
```

There are four inputs to the function file: X, T, WCO, and NP. X is the array of data; WCO is the frequency being filtered; NP is the number of data points in X; and T is a function of NP, T = 1/(NP-1).

In Figures D.1 and D.2, plots of the same data can be seen without the Butterworth filter and with the Butterworth filter, respectively.

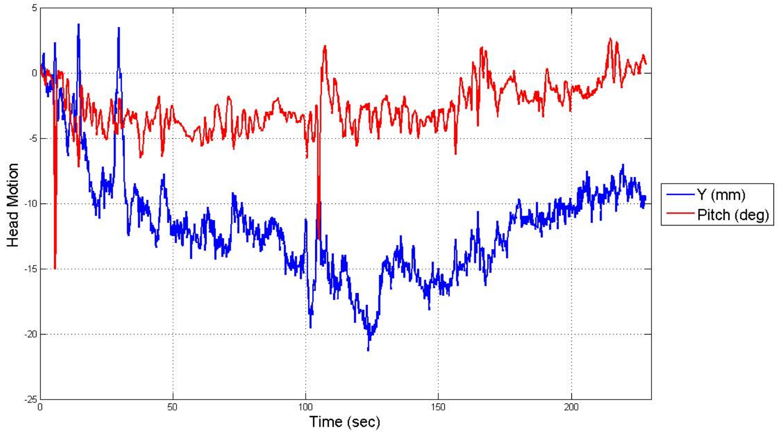

Figure D.1: Data With No Filter

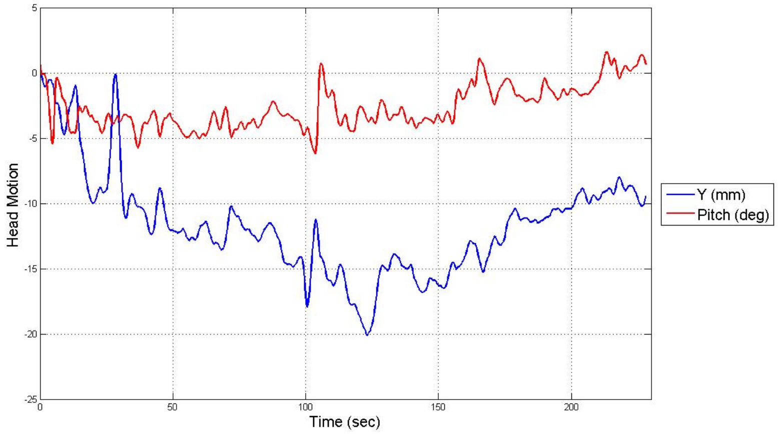

Figure D.2: Data With Butterworth Filter