CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF TRANSPORTATION SCIENCES
Department of Air Transport

Přiblížení v black hole prostředí u začátečníků a zkušených pilotů

Approach in black hole environment in novice pilots and experienced pilots

Bachelor Thesis

Study program: Technology in Transportation and Telecommunications
Study branch: Professional Pilot
Supervisors of the bachelor thesis: doc. Ing. Bc. Vladimír Socha, Ph.D. and Ing. Liana Karapetjan

Eran Belkin

Prague 2022

ČVUT
FD

Rozsah grafických prací: dle pokynů vedoucího bakalářské práce

Rozsah průvodní zprávy: minimálně 35 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)

Seznam odborné literatury: Newman, David G. An overview of spatial disorientation as a factor in aviation accidents and incidents. Canberra City, A.C.T: Australian Transport Safety Bureau, 2007.
Previc, Fred H., et al. Spatial disorientation in aviation. Reston, Va: American Institute of Aeronautics and Astronautics, 2004.

Vedoucí bakalářské práce: **Ing. Liana Karapetjan**
doc. Ing. Bc. Vladimír Socha, Ph.D.

Datum zadání bakalářské práce: **8. října 2021**
(datum prvního zadání této práce, které musí být nejpozději 10 měsíců před datem prvního předpokládaného odevzdání této práce vyplývajícího ze standardní doby studia)

Datum odevzdání bakalářské práce: **8. srpna 2022**
a) datum prvního předpokládaného odevzdání práce vyplývající ze standardní doby studia a z doporučeného časového plánu studia
b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

L. S.

Kraus
doc. Ing. Jakub Kraus, Ph.D.
vedoucí
Ústavu Ústav letecké dopravy

doc. Ing. Pavel Hrubeš, Ph.D.
děkan fakulty

Potvrzuji převzetí zadání bakalářské práce.

Eran Belkin
jméno a podpis studenta

V Praze dne .... 8. října 2021

CTU
CZECH TECHNICAL
UNIVERSITY
IN PRAGUE

Graphical work range:	according to the instructions of thesis supervisor
Accompanying report length:	minimum of 35 text pages (including figures, graphs and sheets which are part of the main text)
Bibliography:	Newman, David G. An overview of spatial disorientation as a factor in aviation accidents and incidents. Canberra City, A.C.T: Australian Transport Safety Bureau, 2007. Previc, Fred H., et al. Spatial disorientation in aviation. Reston, Va: American Institute of Aeronautics and Astronautics, 2004.

Bachelor's thesis supervisor: **Ing. Liana Karapetjan**
doc. Ing. Bc. Vladimír Socha, Ph.D.

Date of bachelor's thesis assignment: **October, 2021**
(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of bachelor's thesis submission: **August 8, 2022**
a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

L. S.

Kraus

doc. Ing. Jakub Kraus, Ph.D.
head of the Department
of Air Transport

doc. Ing. Pavel Hrubeš, Ph.D.
dean of the faculty

I confirm assumption of bachelor's thesis assignment.

Eran Belkin
Student's name and signature

Prague .... October 8, 2021

Abstract

Flying at night is much more dangerous than flying during the day due to a lack of visual stimuli such as the absence of shadows, colors, and topographic references. It is these stimuli that are needed for proper orientation and evaluation of the descent plane. In an optically poor environment, such as approach over a terrain without lighting or the water surface may then select the wrong glide slope and the flight may end dangerously low approach or impact to the ground. Therefore, the work is focused on evaluating descent plane in a typically black hole environment with two groups of pilots; 38 novices in group A and 15 experienced pilots in group B. Within 2 simulated night approaches, the participants were subjected to the black hole illusion environment and a 1-night approach with PAPI, while predetermined performance parameters data was collected. The study identified no significant effects of the black hole environment in terms of piloting accuracy and precision.

Between-group results showed a significantly better accuracy performance of group B when encountering the illusion for the first time.

Keywords: black hole illusion, descent plane, experienced, ideal glideslope, novice

Abstrakt:

Létání v noci je mnohem nebezpečnější než létání ve dne, a to kvůli nedostatku zrakových podnětů, jako je absence stínů, barev a topografické reference. Právě tyto podněty jsou potřeba pro správnou orientaci a zhodnocení sestupové roviny. V opticky chudém prostředí, jako je přiblížení nad krajinou bez osvětlení nebo vodní plochou pak může docházet ke zvolení nesprávné sestupové roviny a let pak může skončit nebezpečně nízkým přiblížením či nárazem do země. Proto práce orientována právě na hodnocení sestupových rovin při typicky black hole prostředí u dvou skupin pilotů; 38 nováčků ve skupině A a 15 zkušených pilotů ve skupině B. V rámci 2 simulovaných nočních přiblížení byli účastníci podrobeni prostředí iluze černé díry a 1 nočnímu přiblížení s PAPI, přičemž byla shromažďována data o předem stanovených výkonnostních parametrech. Studie nezjistila žádný významný vliv prostředí černé díry z hlediska správnosti a přesnosti pilotáže. Meziskupinové výsledky ukázaly významně lepší správnost u skupiny B při prvním setkání s iluzí.

Klíčová slova: iluze černé díry, sestupová rovina, zkušený, ideální sestupová rovina, nováček.

Acknowledgments

I would like to use this opportunity to offer my sincere gratitude to my research supervisors, doc. Ing. Bc. Vladimr Socha, Ph.D.,Ing. Lenka Hanáková, and Ing. Liana Karapetjan for their expert supervision, useful suggestions, and scientific assistance in the development of the current thesis. I want to express my gratitude to all of my fellow student pilots who enthusiastically and with interest took part in the experimental portion of my work. I will always be grateful to my family for their unwavering support, belief in me, and real love as I pursued my education.

Declaration

I hereby declare that I have completed this thesis with the topic “Approach in black hole environment in novice pilots and experienced pilots” independently and that I have attached an exhaustive list of citations of the employed sources.

I do not have a compelling reason against the use of the thesis within the meaning of Section 60 of the Act No. 121/2000 Sb., on copyright, rights related to copyright and amending some laws (Copyright Act).

In Prague on 15.11.2022 ……………………….

Table of contents

List of Figures

List of Tables

List of Abbreviations and symbols

“a” - Actual Altitude

“i” - Ideal Altitude of Glide Slope

“t” - Time spent below ideal glide slope in percentages

“x” - Altitude Difference from Actual to Ideal glide slope

“$\bar{x}$" - Mean Altitude from Ideal Glide Slope

AI - Attitude Indicator

ALTM - Altimeter

ANOVA - Analysis of Variance

ASI- Airspeed Indicator

BHI - Black Hole Illusion

CFIT - Controlled Flight Into Terrain

EV - enhanced vision

GA - Group A

GB - Group B

GPO - Glide Path Overestimation

GS - Glide Slope

HI - Heading Indicator

IFR - instrument flight rules

IGS - Ideal Glide Slope

IMC - instrument meteorological conditions

M1-3 - Measurements

NTSB - National Transportation Safety Board

PAPI - Precision Approach Path Indicator

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RMSE - Root Mean Square Error

SD - Spatial disorientation

SO - spatial orientation

TOT - Terrain Orientation Theory

TTC - time-to-contact

VFR - visual flight rules

VMC - Visual Meteorological Conditions

VR - visual reality

VSI - Vertical Speed Indicator

W/O - without

Introduction

The topic of the thesis is the approach in black hole environment among novices and experienced. In general, flight illusions happen when the pilot's senses and reality conflict. Our sense of sight deteriorates at night, so our brain uses knowledge and experience to make up for it. It is impossible to avoid flight illusions, as both novices and experts encounter them. When practicing approaches under visual metrology conditions, we are taught to memorize a visual representation of the runway at a specific angle, which should enable us to roughly comprehend the slope of our approach with respect to the runway. We encounter the black hole illusion under the same circumstances at night, without ambient lighting or any indication of our approach gradient. The illusion causes the pilot to believe that he is too high; therefore, the pilot tries to fix this by flying lower than necessary, which raises the possibility of a terrain collision.

The goal of this study is to analyze the present state of knowledge about black holes in general and among pilots with various degrees of expertise. The field's limitations will also be discussed, along with suggestions for how to overcome them. Past training and experimentation have not focused much on the black hole illusion.

Based on this, the thesis will further the investigation into the matter by conducting an experiment using a simulator and doing a thorough analysis by following a group of novice pilots and a group of experienced pilots who will be exposed to the illusion's environmental conditions. Data relevant to their performance in the descent plane will be recorded, statistically analyzed, and the outcomes will be presented, discussed, and concluded.

Chapter 1 – Current State of the Art Analysis

1.1 Literature review

The issue of black hole illusion (BHI) is complicated by multiple variables, necessitating a thorough examination of the subject. Apart from aspects related to the illusion itself, the overall performance and quality of the notions are also worth evaluating. Nonetheless, the current assessment is constrained by the low quantity of scholarly literature available that describes the topic.

1.1.2 What is the black hole illusion?

Before getting into what characterizes a black hole approach, let's first define a black hole. A black hole is a location in the cosmos where the gravitational field is so powerful that not even light can escape. Small black holes may have formed during the Big Bang, but larger black holes are formed when a star collapses in on itself, known as a supernova, and pieces of the star are blasted into space [1].

The term "black hole" refers to the topography beneath the airport's approach, not the actual airport. Simply described, a blackhole approach is a long, straight-in approach across featureless and unlit terrain at night to a brightly lit runway. Many pilots, both novice and experienced, have died as a result of the black hole approach over the years. Flying at night has always been riskier than flying during the day, owing to the lack of perceptual cues that we all rely on to keep the shiny side up [2].

Undoubtedly the most fundamental of all human behaviors, spatial orientation (SO) incorporates a wide range of diverse sensory, motor, and brain systems. Spatial disorientation (SD) is the inability to retain SO, which may be catastrophic in flying environments all too often.

In the context of aviation, SO mostly relates to our knowledge of our position and motion with respect to earth-fixed space rather than to specific locations on earth. [7]. To make sense of the world and direct our behavior, we use mental models as a framework. Mental models may be inaccurate and insufficient. In aviation, the discrepancy between our perceptions and expectations is an illusion. In other words, the gap between reality and perception. When viewed from the air, objects appear very differently than when seen from the ground. The pilot is at a disadvantage due to the lack of constant visual references and the potential for incorrect mental models to be created. Additionally, the pilot's cognitive and sensory orientation mechanisms must attempt to adapt to a third dimension for which they were not originally intended while in flight. Both mental and physical illusions will result from this. Pilots with all levels of training and experience are susceptible to illusions at any time during a flight. Therefore, the pilot needs to be aware of the potential for erroneous information interpretation. All our senses can be affected by illusions, but those that affect vision and the middle ear's balance organs are of particular concern when flying. We also have a position sensing system that derives from nerve endings in the skin, muscles, and joints, and this system has the potential to provide the brain with inaccurate information. Because we typically believe our visual input to be the most reliable of our senses, visual illusions are especially dangerous in the aviation industry. According to statistics, spatial disorientation contributed to 37 % of general aviation accidents and 12% of commercial air transport accidents. This is one of up to 80% of fatal accidents directly caused by spatial disorientation. Additionally, an analysis of the United States Air Force (USAF) found that of all mishaps, 11% are attributed to SD and that SD accounts for 23% of accidents occurring at night. The USAF found 79% of pilots reported BHI was the second most common occurrence of a possibility of 38 visual/vestibular types of SD. In another survey, they found that the leading cause of visual SD in multi-engine aircraft was the BHI. For all types of USAF aircraft, the BHI was the third most cited type of visual SD [6,37]. Illusions such as a false horizon or a mismatch between instrument data and what the eye sees might result from a loss of perspective. This is especially true while flying over water at night, and it might result in an incorrect height determination. Pilots may opt for a visual approach because it seems correct, even though they would be far better off depending on their instruments. It can often lead to glide path overestimation (GPO) due to a lack of visual references to guide them [1].

Dr. Gibb, a former pilot and retired colonel in the United States Air Force, detailed the optical misconception that happens when a pilot is induced into GPO in a featureless area (Figure 1.1). GPO occurs when a pilot has the erroneous impression that the aircraft is flying too high, above the desired 3° glide path, or "feeling steep." Pilots make a hasty descent, mistrusting their perceptual abilities, and incorrectly adapting to an unsafe position below the desired glide path. The BHI, as previously stated, relates to the environment surrounding the runway rather than the runway itself. GPO produces a concave-shaped approach, a below-glide path arc, which may result in contacting terrain or an obstacle ahead of the runway, as indicated in the diagram [5].

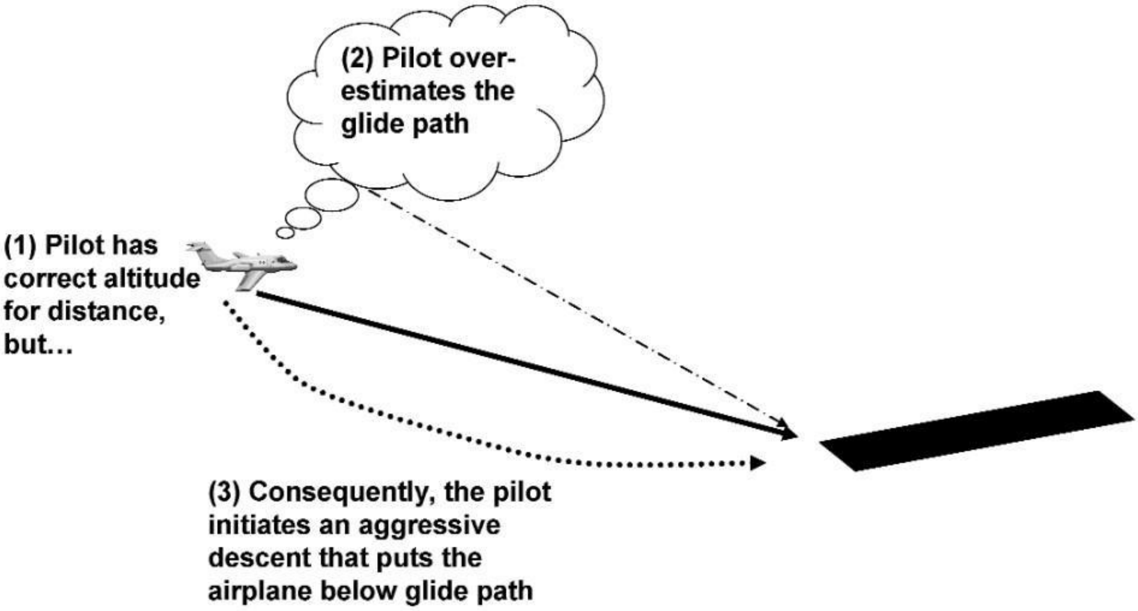

Figure 1.1: Black-hole diagram [5]

1.2 Factors contributing to the black hole illusion

The black hole effect is amplified in several circumstances. An airport on the outskirts of a well-lit city, with few or no landscape features or lights between the pilot and the terminal. The brightness of the city lights will make them appear closer than they are. An airport on the coast or in sparsely populated areas such as deserts or natural areas. This is a classic example of a black hole. The landings at Los Angeles International Airport to the east (Figure 1.2) and Salt Lake City International Airport to the south (Figure 1.3) [3].

Figure 1.2: Los Angeles International Airport night approach runway 06 [35]

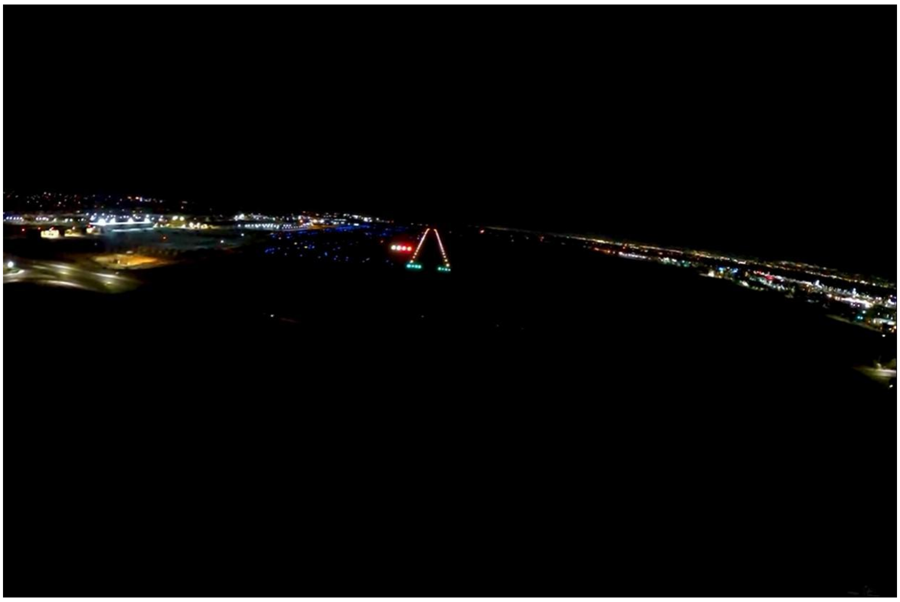

Figure 1.3: Salt Lake City International Airport, runway 16 [36]

Reduced visibility due to low clouds, mist, or precipitation can exacerbate the illusions and inherent hazards of night visual techniques. The most basic danger of poor visibility is that objects appear to be further away than they are. Even in near-perfect sight, there are still dangers to be aware of. The bright lights that surround a "city" airport might readily obscure the obstruction warning lights on any nearby mast or tower. Regardless of the conditions, vigilance during the night approaches is essential.

On a clear night, lights can be seen from a considerable distance, making distance estimation difficult without the use of specific landmarks or electronic aids. As a result, starting descent for a straight-in approach purely based on runway lights may be premature, resulting in a fall below a safe altitude controlled flight into terrain (CFIT) mishap [3].

The width of the runway and the approach's initial altitude are additional contributing elements. Glide path altitude error was significantly higher in a longer runway and a lower starting altitude condition in an experiment where participants had to fly a nighttime approach as close to 3° as possible [9], which supports the theory of GPO that was previously discussed [10].

In 1954, according to Calvert, who coined the phrase "black hole illusion," claims that lack of texture and horizon have a significant role in the BHI. Calvert describes it as skiing in a snowstorm. This claim also describes how a runway looks when landing an aircraft on a misty night or during grey featureless daylight [11]. Therefore, when designing simulators, it is important to consider enough intermediate texture on the screen to allow correct height judgment [41]. At night we lose some of the visual guidance of the approach due to the absence of the horizon. Pilots might attempt wrongly same-day strategies at night. They may attempt to use the horizon as a cue during a nighttime approach by inferring an implicit horizon by estimating its location through available information. According to a thorough study by the US army, pilots may be biased when estimating the implicit horizon based on the vanishing point from the parallel runway lines. The study's hypothesis was: *" … in the absence of a true horizon the perceived intersection of the runway lines serves as an estimate of the horizon. To the extent that this estimate is biased, the pilot may fly an inaccurate glide path…"* (Figure 1.4) [40].

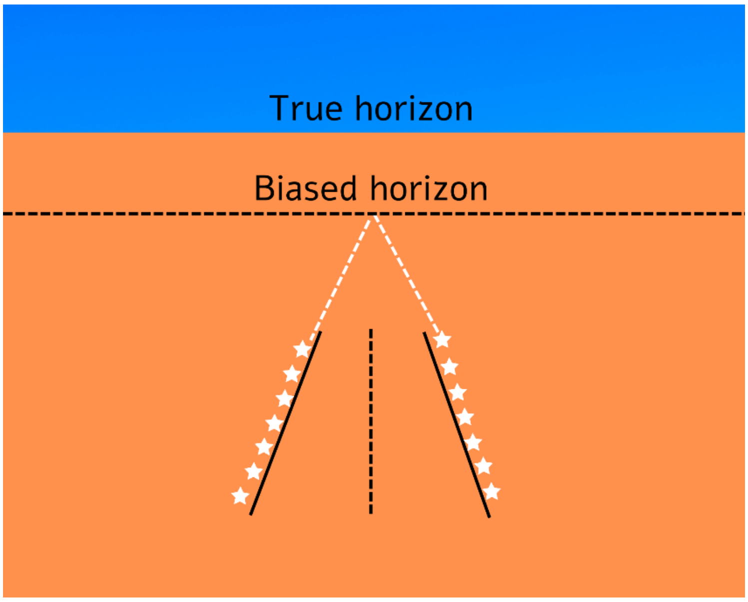

Figure 1.4: True and biased horizons

The illusion of a black hole can also be created by a poor approach strategy. In the Beech 65-A90-1 crash, during the approach, it's probable that the pilot did not maintain a sufficient crosscheck of his altimeter and radar altimeter, and that the copilot failed to keep monitoring the airplane's position. [44]. The choice of the initial approach altitude is another consideration; starting too high or too low is inappropriate. According to one study, when pilots start approaching too high in comparison to the 3° ideal glide slope (IGS), a steeper glideslope—which is consistent with the BHI—happens [19]. A different study contends that starting at low altitudes results in worse BHI effects [9].

Fatigue, in addition to other human factors, plays a significant role for obvious reasons. Fatigue is common in most night-flying missions since our bodies prefer to sleep during the hours of darkness. Fatigue impairs reaction time, focus, and decision-making abilities. Pilots should be aware of how acute or chronic fatigue might affect motor skills and judgment. Fatigue isn’t a direct factor for BHI, nevertheless, it makes pilots more susceptible to a BHI during flying [4].

Since the dawn of aviation, pilots have known that flying at night is riskier than flying during the day. Flying at night in good weather is closer to flying in IMC than it is to flying in VMC. Because rod cells in the retina of the eye are more sensitive to very weak light energy, they will be doing the majority of the work due to the low light level. Unfortunately, the rods only allow for viewing black, white, and gray. Because color variation accounts for so much of the perception of size and distance, pilots are already at a disadvantage. At night, terrain and clouds can be difficult to notice until it's too late, and ground lights can be confused for stars and horizons, as previously said.

What makes the black hole approach so unusual and deadly is that using the attitude indicator, altimeter, and turn coordinator will not instantly alert the pilot of the issue. Pilots who fall prey to the BHI believe they are on the appropriate glide path, and everything is fine until it is too late. Second, even if it is understood cognitively that the illusion is taking place, a false sense of compulsion to believe the delusions occur. Through training, there is no way to avoid feeling this illusion. It will happen, just like hypoxia, and the best protection is awareness and avoidance [2].

According to a 2018 study on the impact of cockpit eye position on flight altitude during the final approach to landing, sitting posture has the potential to be the straw that breaks the camel's back. A pilot's less upright posture, possibly as a result of fatigue from a night flight, may result in a lower eye position. This could lead to a lower approach that goes undetected due to the lack of visibility. Recognizing this risk factor and sitting more upright may help reduce the risk of fatal consequences [8].

1.3 How to handle the black hole illusion

To handle the BHI, it can be resolved in terms of the pilots' attitude during landing and the aerodrome's approach facilities. This paragraph will describe the comprehensive behavior of the pilots from the pilot side of the equation. The aerodrome section will refer to the ground landing aids available to pilots during non-precision approaches. A modern study from 2021 that covered and supported all research on the topic presents three potential strategic approaches to dealing with BHI. The perception of the landing point and the awareness of a texture gradient are two environmental factors that the study claims are the first and primary causes of BHI. According to the Terrain Orientation Theory (TOT), the perceived orientation of the ground terrain governs the approach to landing. The texture of the terrain surface and the presence of 3D objects (like trees and buildings) in the runway environment serve as visual cues for perceived orientation. For the TOT The surrounding landscape and surroundings are made up of both global and local elements that make it possible to judge how the landing surface will be oriented from a distance and up close during a visual approach to landing. According to TOT, topographic characteristics can compensate for a runway's variable dimensions and lack of a horizon. According to TOT, runway approach lighting systems designed to show surface orientation and reduce runway ratio perception may encourage steep approaches at night and minimize mishaps caused by BHI [43]. In line with the TOT, the modern study recommends the following strategies;

- pilots should pay more attention to the terrain conditions of the destination, especially when it is unfamiliar [43].
- When city lights are located higher than the runway altitude in the distance, pilots should fly lower than normal, not a shallow approach.

- Maintaining a stable approach altitude and angle are recommended in night flying unless the approach altitude is cross-checked incorrectly.

The second strategy for overcoming the illusion is systematic training. It is claimed that even experienced and novice pilots won't be able to completely avoid the BHI, according to a 2013 study. It was suggested that an effective strategy to deal with it would be to use enhanced vision (EV) technology. A system called an EV creates a live image of the environment using imaging sensors [45] (figure 1.5). The difficulty of tracking and analyzing the illusion after real-time detection is another argument that contributes to the challenge of gathering trustworthy and ongoing data. Additionally, the lack of reporting by the pilots themselves limits the database's volume and makes it challenging to learn and enhance the performance curve under the effect of the BHI. Further research should be conducted on any unreported or unidentified accidents or events that could be connected to the BHI. In the past, studies have often used non-experimental techniques, including surveys, interviews, and study of accidents and incidents. But post-incident investigations frequently restrict BHI research to pilot reports, which reduces the study's potential application. Unreported accidents and occurrences may potentially be a result of BHI fatalities and a reluctance to discuss personal experiences with flying illusions. In order to capture and evaluate the BHI more accurately and sensitively in lab studies or even real-world situations, it was recommended that objective metrics be created [30].

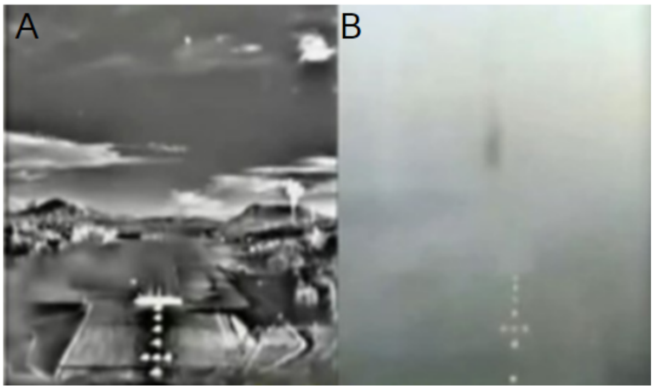

Figure 1.5: With EV (A), without EV (B) [45]

The third approach is linked to the preceding chapter's discussion of the selected pilots' strategies, which are crucial to a safe landing in a BHI situation. Depending on their cognitive state and the visual circumstances outside the cockpit, pilots may automatically transition between several perception techniques. A pilot's ability to predict the time to contact (TTC) during an approach or landing might be enhanced by the texture of the terrain. If just runway outlines were provided, pilots might convert from a TTC estimate to an altitude perception method. However, the height perception technique is less reliable and riskier during the approach under BHI circumstances since the fundamental indication of visual angle is inconsistent [13]. Important findings on the behavioral level have shown that there was still a high willingness to continue VFR-IMC even when the environment deteriorated. According to the study, in order to reduce the effects of BHI, pilots should utilize instrument flight rules (IFR) during the approaching phase and visual flight rules (VFR) during the landing and touchdown phases [30].

The current standard, probably the most efficient and common tool used in aviation for landings is the precision approach path indicator (PAPI). The PAPI assist the pilot keep height awareness with relate to the ideal GS (usually 3°) and establishing a stabilized descent. In BHI environment the pilot can focus on the PAPI instead of creating a biased glide slope on terrain and horizon. The system consists of 4 lights usually in a row perpendicular to the aiming point. The lights illuminate red or white steady flashes. The system is common and very economical due to the transition of the lamps to LED. The transition benefits include requiring less energy and extension of the PAPI lamps from 2,000 hours to at least 40,000 hours [41]. If the pilot is on the correct path, s/he will notice 2 white and 2 red colors while looking at the PAPI. If there are more than 2 white lights, it indicates the pilot is above the IGS, and vice versa if more than 2 red lights, as described in figure 1.6 [42].

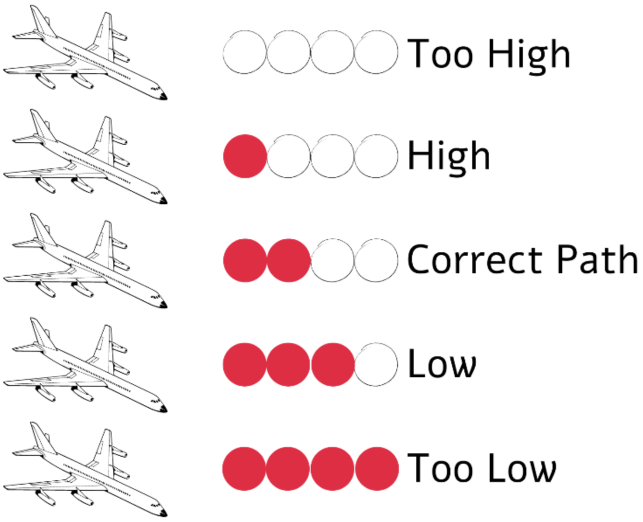

Figure 1.6: PAPI principle

1.4 Limitations of the current state

The inability to track the illusion in real-time, both in terms of the technological system installed in the aircraft and in terms of pilot reports, is a significant limitation, as was already mentioned. Additionally, the process of improvement is delayed by unreliable information-gathering techniques. Research hasn't shown much interest in studies on the BHI. Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, a recent systematic review that used the term "Black Hole Illusion" only found 14 articles (31). Results showed that earlier BHI-related studies were limited and did not fully investigate factors that might affect the BHI. Although accidents and incidents highlight their importance, this flight illusion is not mentioned in The Oxford Compendium of Visual Illusions (32). Furthermore, despite the publication of two recent studies (33), no significant advancement in the field has been made since the first author's dissertation on the subject was finished in 2013 [30].

Nowadays, a flight simulator is commonly used for aviation experiments in favor of cost, ease of implementation, and efficiency. Although having high physical fidelity, flight simulators are often unable to reproduce a cognitively stressful flying experience. Participants in Reuter's study performed better in the flight simulator and found it challenging to apply their knowledge to actual flight situations. Given that stress is a common component of aviation operations, it can be further subdivided into biological, psychological, and social psychological levels using a challenge and threat model, a stress-free environment might not accurately simulate real flight scenarios [20]. Another con is that the simulator is not beneficial for investigating BHI mechanisms. It cannot sense real-world spatial relationships from only visual information [34].

A study contained twenty pilots who flew simulated approaches under various visual cues of random terrain objects and approach lighting system (ALS) configurations whereas BHI conditions. The 20 volunteer pilot participants fell into two groups: 8 experienced and 12 novices. The 8 experienced pilots ranged in age from 34 to 48 years (mean = 42.1) and in flying hours from 2000 to 15000 hr (mean = 6238, median = 4000). The 12 novice pilots ranged in age from 18 to 27 years (mean 21.4) and in flying hours from 75 to 527 hr (mean = 256, median = 284). Performance was assessed relative to the desired 3° glide path in terms of precision, bias, and stability. Unexpected results were obtained using the expertise variable. In the random terrain manipulation, there was a difference between experienced and novice pilots in terms of precision and bias, but not in the approach lighting manipulations. Furthermore, compared to novice pilots, experienced pilots flew much lower below the desired glide path. It was argued that the experienced pilots began their descent sooner because they were overconfident in their abilities. The position of the novice pilots in relation to the runway and their delayed descent, however, was less certain (both vertically and horizontally). The fact that the more experienced pilots were older should be mentioned as a potential confounding factor. In terms of stability, the pilots' level of experience was crucial (standard deviation). Surprisingly, novice pilots were more stable. It was suggested that this could be attributed to generational differences in comfort levels with computer game joystick controls and/or Microsoft Flight Simulator. One could also make the case that more experienced pilots might have found it difficult to control the simulator without the use of the throttles and lateral control inputs. However, a closer look points to a different performance strategy. As they try to determine the saliency of cues when flying in poor conditions, pilots face a great deal of uncertainty. The appearance of instability may have been caused by the experienced pilots actively changing their pitch inputs to better understand the visual cues in the environment [5].

1.5 Chapter Summary

It follows from the above that there is a lack of BHI- related studies and enhanced advice to continue the research regarding the comparison between different levels of pilots in the BHI environment. Therefore, the thesis will investigate how experienced and novice pilots perform differently. This will be accomplished using a simulator, which will create a setting that mimics the illusion of the black hole. The experiment will concentrate on the descent plane, which is greatly impacted by the illusion and increases flight risk.

Therefore, the main objective of the current thesis is to ascertain what modifications take place in the descent plane for both novice and experienced pilots during night approaches on the simulator in an environment typical for approach, through a black hole. Multiple consecutive partial goals make it easier to reach the desired goal.

The first partial goal, which has been achieved by the state-of-the-art evaluation, was to thoroughly review the materials available for the topic and to highlight specific points of interest. The development and experimental verification of acceptable methodology for the piloting of performance assessment in the field of BHI is the second partially achieved goal. The third partial goal is to use the aforementioned methodology for a controlled measurement of participant groups that are similar in order to evaluate the effects on piloting performance. Applying appropriate statistical techniques to evaluate the results and explain the changes seen is the fourth partial goal. Thus, based on the goals set, the present thesis aims to answer the following research questions:

1. What changes occur in the descent plane during night approaches on the simulator in an environment typical of black hole approaches for novice and experienced pilots?

2. Are there within-group differences developments under BHI approaches?

3. Is there any difference in descent plane performance in black hole approaches between the groups?

Chapter 2 - Methods

The methodology described in this chapter was established in order to be able to overcome the limitations of the findings of the current state of the art. Here is a description of my own method for testing two groups of pilots' descent planes in a typical black hole environment. It thoroughly explains the entire experiment, the tools used, and the software subjects. Additionally, this article describes the techniques for analysis and data evaluation.

2.1. Participants

In this thesis, based on expertise, the subjects were assigned to one of the two following groups: Group A (GA) and Group B (GB). GA consisted of 38 novices and GB 15 experienced pilots. While the initial aim was to involve an equal number of people for the two groups, finding participants, especially for the experienced group, has proven to be difficult. GA ranged in age from 19 to 25 and in flying hours from 80 to 250 hours (mean = 181, median = 200). GB ranged in age from 26 to 65 and in flying hours from 345 to 13,000 hours (mean = 4,023, median = 1,250). All the participants had already accumulated varying levels of actual flying experience during their studies before the data collection commenced. While just a few participants had obtained their pilot's licenses, it is important to note that all the subjects had been endorsed to perform solo flights day and night (without an instructor on board). Since all class 1 medical certificate holders, issued in accordance with Commission Regulation (EU) No 1178/2011, Annex IV (Part-MED), had normal visual acuity, and any vestibular visual disturbances were ruled out. All 53 subjects filled out a questionnaire before and after the experiment, which will be detailed in the following chapter. Prior to the experiment, all participants signed informed consent with the details that all information had been sufficiently explained and was voluntary.

Participants were not informed of the experiment's goals in order to generate trustworthy instinctive reactions to the black hole illusion and to prevent factors that might affect their performance. Prior to the trial, participants were asked to complete a questionnaire that was intended to ensure that their physical and medical conditions were uniform and, more specifically, to rule out any conditions that might impair night vision.
The questions were as follows:

1. Which types of aircraft did you fly and how many flight hours do you have on each one?
2. How many night flight hours do you have?
3. When was your last flight?
4. When was your last night flight? On which AC did you fly at night?
5. Do you wear glasses while flying? Num.
6. If you smoke, how much do you smoke per day?
7. Are you drinking alcohol? When was the last time you drank alcohol? How much alcohol do you drink every day?
8. How many hours did you sleep last night?

In addition, the participants needed to answer another questionnaire after the experiment, in order to analyze their basic knowledge regarding BHI and to check if they distinguished the differences between the approaches with and without the PAPI. The questions were as follows:

1. Did you feel like you did something wrong?
2. Did you feel any difference from the day approach?
3. Did you study the black hole illusion in your training?

4. What is the black hole illusion?

2.2. Procedure

Due to the nature of the bachelor's thesis study, the flights were simulated. However, to achieve a higher level of immersion and awareness, a virtual reality (VR) kit was used. The airplane utilized throughout the research was a Beechcraft Baron 58.

Every experiment was preceded by a basic explanation of the cockpit features (indicators) to ensure the subjects’ ability to correctly interpret the flight parameters required. The subject was initially given at least one opportunity to take a day approach before the necessary data were collected. Its goal is to get the subject to feel at ease using the experimental equipment—a VR simulator and the stick—in order to gather accurate data and at least a basic level of flight capabilities. The subject was given another chance if his performance wasn't convincing and/or if he tried a different strategy to get familiar with the simulator and emulate it. This continued until it was agreed upon by both parties.

The experiment included two types of night approaches and three measurements in total. This aircraft has been set into the correct QNH, the heading bug is set, and the landing gear is extended. So, the only thing you have to deploy by yourself is the flaps. You’re now eight nautical miles away with an altitude of 4500 feet from runway 29 threshold of Karlovy Vary airport in the Czech Republic (ICAO code: LKKV) in the correct attitude regarding the 3° IGS. The runway elevation is 2000 feet AMSL. The weather throughout the experimental process was set to VMC (Visual Meteorological Conditions) with a visibility of more than 10 km with no clouds, wind, or turbulence. To preserve the settings of weight and balance remained unchanged to preserve the handling characteristics of the airplanes. Your mission is to fly the aircraft with an IAS of 110 Kt with continued gliding to land on the runway. At this speed, you can deploy the flaps safely as you need. For execution, they have at their disposal the six basic analog gauges.

Two different night approaches and a total of three measurements were used in the experiment.

The first approach and measurement characteristics were under nightlight and ambient lighting that was intended to create the BHI, as shown in Figure 2.1A The only lights visible were a part of the runway's side lights, and there was no ambient lighting. There were no landing aids.

On the second approach, it was nightlight, but there was ambient lighting and PAPI close to the runway threshold on the left, as seen in Figure 2.1B. The aircraft is in the same spot and initial position as during the first approach.

The third measurement was a repetition of the first approach so that it could be an indication of the effect of the subject's visual memorization ability after he was given the opportunity in the second measurement to use PAPI.

The predetermined parameters, approach light system, and indicators involved are summarized in Table 1.

Table 1. Predetermined measurements parameters

	M1	**M2**	**M3**
Heading (°)	290	290	290
Altitude (AGL) (ft)	2500	2500	2500
Vertical speed 9ft/min)	300	300	300
Airspeed (kt)	110	110	110
Instruments required	ASI, ALTM, AI, HI, VSI	ASI, ALTM, AI, HI, VSI	ASI, ALTM, AI, HI, VSI
Approach light system	-	PAPI	-

“-” - parameter was not subjected; M1-3 - measurements; ASI- Airspeed Indicator; ALTM - Altimeter; AI - Attitude Indicator; HI - Heading Indicator; VSI - Vertical Speed Indicator; PAPI - Precision Approach Path Indicator

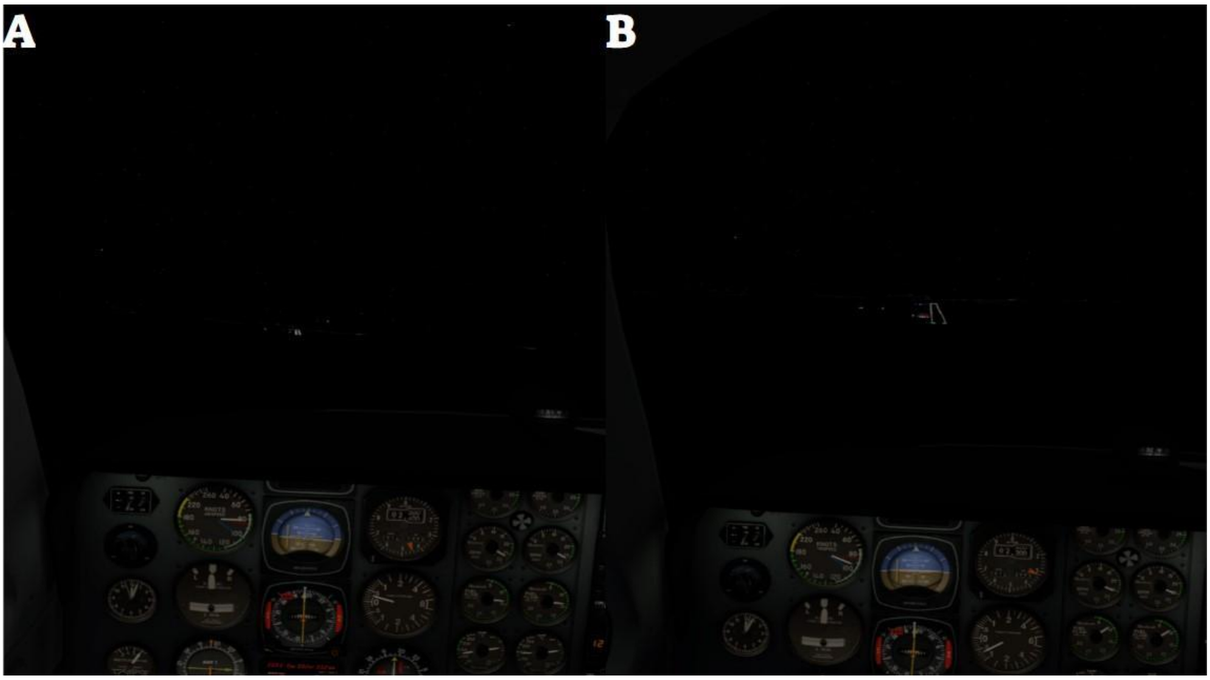

Figure 2.1: Night approach without PAPI 8 NM (A) and with PAPI 4 NM (B)

2.3 Equipment

As previously mentioned, the experiment involved simulated flights utilizing VR. Therefore, a basic physical cockpit framework was incorporated, consisting of a pilot’s seat, primary flight controls (a yoke and rudder pedals), and a throttle quadrant. It is shown in figure 2.2A that such a setup enabled basic flight control inputs by the participant, which was sufficient for the maneuvers to be executed. If needed, more advanced interactions within the cockpit (for example, heading bug adjustments) were performed by a separate human operator. The software used for flight simulation was X-Plane 11 (Laminar Research Ltd., Columbia, South Carolina, USA). Models of the airplanes flown are available by default with the simulator. The VR environment was supported by a FOVE0 VR headset (FOVE Inc., Tokyo, Japan). This whole system is controlled from the instructor’s workplace. The workplace is located near the simulator and is electrically and single-connected to the simulator gear. The instructor, therefore, has the necessary equipment, i.e., computers, alternative control consoles, recording equipment, etc. The workplace is shown in figure 2.2B.

Figure 2.2: A participant at the VR Cockpit setup (A) and simulator workplace (B)

2.4. Data Collection and Processing

As has been previously mentioned, the process of data collection was performed for the purposes of piloting performance evaluation. Piloting precision data was recorded.

2.4.1. Flight data collection and processing

The piloting performance data was derived from a recording of various flight parameters (as per Table 1) within the simulator. For the purposes of this work, the analysis and data evaluation was performed using the following parameters: height and position. This process was facilitated by inbuilt software capabilities. The monitored flight parameters were collected continuously throughout the flights at a sampling frequency of 5 Hz. Efforts were made to keep the data representation and its quality consistent. Therefore, the participants were given time to achieve a stabilized condition according to the parameters required before the data collection for the given approach was initiated. The final selection of the flight parameters assessed for the measurements was governed by the desired glide path, even though certain conditions allowed for more data to be considered. The main goal of the thesis is to find out what changes occur in the descent plane during the night approach. Therefore, parameters regarding the descent profile were the most useful to extract from the data.

The flight data initial processing, similarly to all calculations performed further, was done in the MATLAB environment (MATLAB R2021a, MathWorks, Inc., Natick, MA, USA). A basic script was created to compute the following four metrics for every difference between an IGS of 3 degrees and the actual GS: mean altitude, standard deviation (SD), root mean square error (RMSE), and time spent below the IGS in percentage. These four measures are essentially proposed as indicators of piloting performance within this research. RMSE will indicate the accuracy, SD will manifest the precision, mean and time below IGS will give a general indication of the performance since its reliability is neither accurate nor precise as the to previouse indices mentioned. The procedure to describe those calculations is described below.

Where I_i represents the IGS altitude, a_i is the actual altitude, and x_i is the difference from the IGS.

$$x_i = a_i - I_i \tag{2.1}$$

The mean value of the whole differences "$\bar{x}$" is given by equation 2.2, dividing the sum of all whole differences by "N" - representing the total number of altitude dataset points and "x_i" is the value of the i^{th} point in the data set:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2.2}$$

The (SD) is a statistic that measures the distribution of a dataset relative to its mean and is calculated as the square root of the variance. The SD is calculated as the square root of variance by determining each data point's deviation relative to the mean. If the data points are further from the mean, there is a higher deviation within the data set; thus, the more spread out the data, the higher the SD.

$$s = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}} \tag{2.3}$$

A RMSE is calculated to understand the relationship between a predictor variable, i, and a response variable, a RMSE is calculated. It is a way to assess how "good" a model fits a given dataset, which is a metric that tells us how far apart the IGS is from the actual altitude values, on average. The formula to find the RMSE is as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N} (x_i - I)^2}{N}} \tag{2.4}$$

The last equation was for the time spent below the IGS in percentages presented by “t”, where N_b is the data points below the IGS divided by the total data set points N:

$$t = 100 * (N_b/N) \tag{2.5}$$

2.5. Statistical Analysis

Due to the nature of the experimental setup and the different measurements involved, several analysis approaches were incorporated, depending on the investigated issue. Thus, the present statistical assessment is split into 2 main branches between the two groups according to the following objectives: a general comparative analysis of the piloting performance within the groups and then between groups.

2.5.1. Comparative analysis of piloting performance within the groups

Since GA and GB were tested in the same manner using the same experimental setup, a general comparison of the piloting performances of the two investigated groups can be used to ascertain whether there are any appreciable differences. It mainly purports to find out the differences in the two groups' descent plane. This part of the statistical analysis deals with a set of data from repeated measurements, with the objective being to determine any statistical significance in between. The data sets' normality was not universally confirmed, limiting the use of parametric tests.

Therefore, a decision to resort to non-parametric tests for the present part of the statistical analysis was made. These took the form of the ANOVA (analysis of variance) Friedman test. The Friedman results were assessed using an alpha value of 0.05 [37].

Defined null and alternative hypotheses, where:

$H_0; there\ is\ no\ difference\ between\ the\ three\ measurements$

$H_1; there\ is\ a\ difference\ between\ the\ three\ measurements$

2.5.2. Comparative analysis of piloting performance between the groups

Taking into account the aforementioned subject variability factors, the following assessment between groups will evaluate the general performance effect on the different groups as a result of the BHI in its primary focus. Thus, the aim is to determine whether the performance has increased, decreased, or stayed unchanged as a result of the variation in pilots' experience. Therefore, the current analysis will deal with sets of paired values. Since the data did not belong to a normal distribution, the use of parametric tests was rendered impossible. Thus, the process of determining whether a statistically significant difference is present was facilitated by means of the Wilcoxon rank-sum test, known also as the Mann–Whitney U test (essentially an adaptation for two independent samples) in the case of between-group comparison [38]. This approach was repeated with GA and GB per every measurement investigated. The Wilcoxon rank-sum results were assessed using an alpha value of 0.05.

Defined null and alternative hypotheses, where:

$H_0; there\ is\ no\ difference\ between\ the\ paired\ measurements$

$H_1; there\ is\ a\ difference\ between\ the\ paired\ measurements$

Chapter 3 - Results

Results obtained during the process of statistical analysis are presented in this chapter. They are categorized into the two following groups: comparisons within GA and GB, and comparisons between GA and GB. Box plots are widely used within this chapter for data presentation; henceforth, their legend is as follows: The red line indicates the median, the blue rectangle marks the first and the third quartiles below and above it, respectively, and the black whiskers correspond to 1.5 times the interquartile range, and any red crosses indicate outliers.

3.1. Within-group comparison

3.1.1. Group A

Overall, the Friedman test did not show significant changes within the group, neither in terms of mean (p = 0.1905), SD (p = 0.351), RMSE (p = 0.0712), nor the percentage of time spent under the IGS (p = 0.9226). Thus, the null hypothesis was far from rejected.

Although Friedman’s test didn’t reveal significant differences, some patterns are noticeable, as can be seen in the boxplots in figure 3.1. The three height mean deviations have a strong tendency to deviate from the IGS line, with the median, upper, and lower quartiles all falling below the x-axis. The graph that depicts the percentage of time spent below the IGS, which ranges from roughly 60% to approximately 90% of the time between the upper and lower quartiles of the boxplots, supports this. The second measurement with the PAPI demonstrates that the approaches were more stable because the range of the boxplots for the mean, RMSE, and time below is smaller than it was for the approaches without the PAPI. The most significant change in the SD is the gradual expansion of the distribution from the first to the third measurement as its range increases, indicating a deterioration in performance. The gradual expansion of the distribution from the first measurement to the third measurement results in the most significant change in the SD, which is in some ways contrary to the other measurements that show a subtle trend of performance improvement over time. Due to the box's downward skew and the presence of seven outliers, this degradation can be questioned.

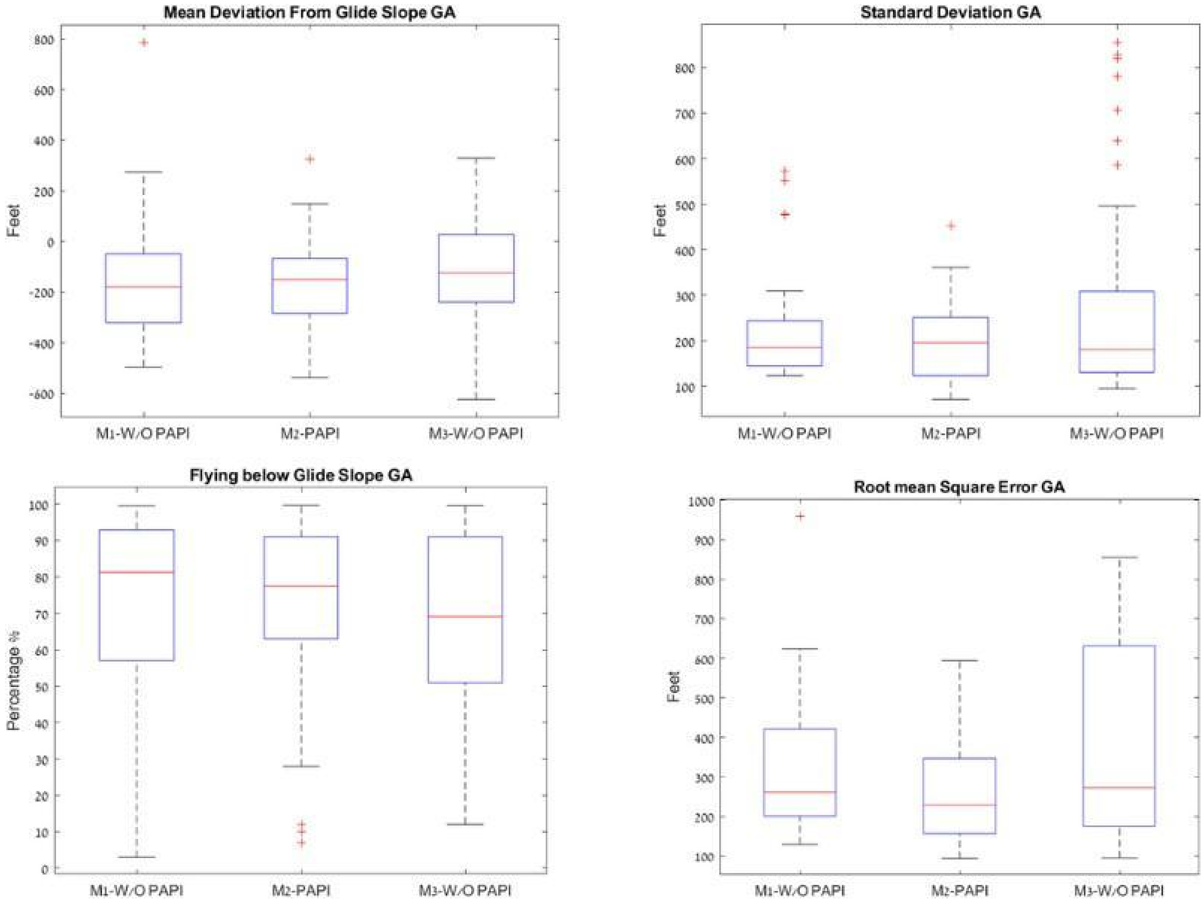

Figure 3.1: within boxplots analysis of GA

3.1.2. Group B

Like GA, the Friedman test did not show significant changes within the group, neither in terms of mean ($p = 0.6271$), SD ($p = 0.1576$), RMSE ($p = 0.7589$), nor the percentage of time spent under the IGS ($p = 0.3438$). Thus, the null hypothesis was far from rejected.

The noticeable patterns, as can be seen in the boxplots in figure 3.1, are an overwhelming tendency to fall below the IGS, with the median, upper and lower quartiles all falling below the x-axis. The M2's short range in comparison to the other measurements gives it the most stable flight performance in all tests. This demonstrates the PAPI's assistance. It is clear that the flight without PAPI was riskier because the pilot had a wider margin of error and tended to fly 150 feet lower than the M2. The decrease in performance during the illusion is confirmed by the fact that the range of error was wider when they were exposed to BHI, as shown by RMSE.

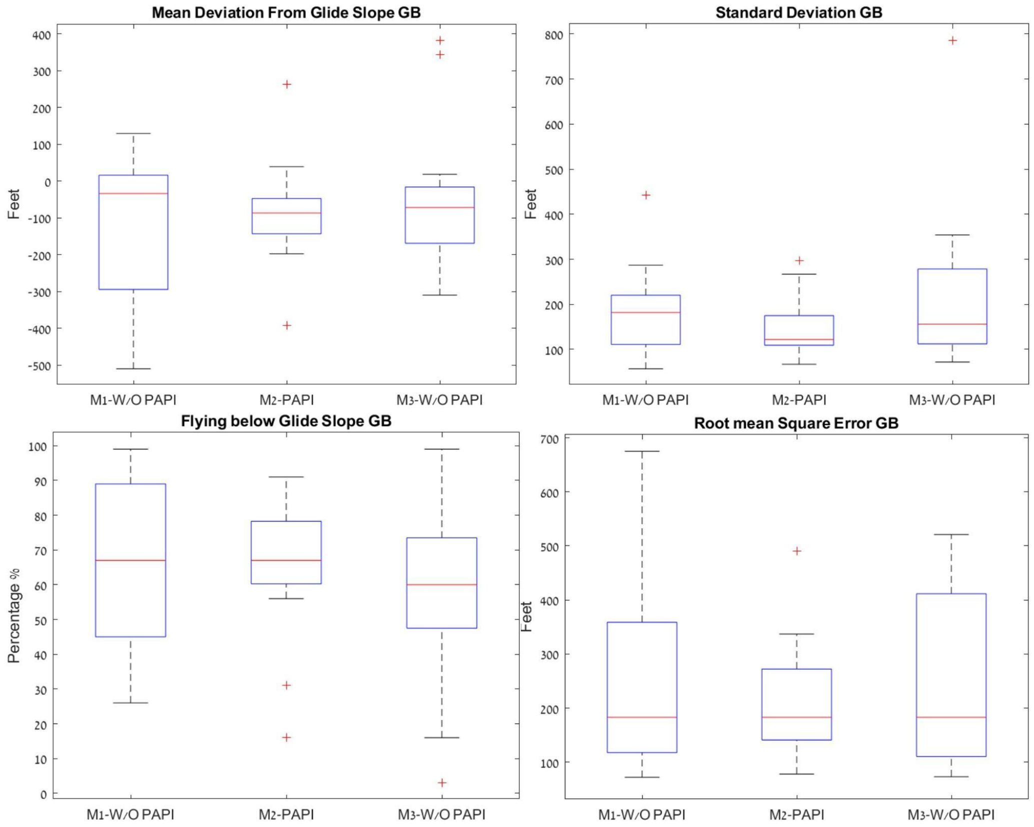

Figure 3.2: within boxplots analysis of GB

3.2. Between-group comparison

The following results detail the findings after a comparison of each group separately using the repeated measures Wilcoxon rank-sum test (known as Man-whitney U test), and a boxplot presentation between the paired measurements will be presented for each parameter.

3.2.1. Mean

The results of the mean altitude deviation assessment are presented in Figure 3.3. Five participants were found to be extreme outliers, but otherwise this parameter was unremarkable: no statistically significant differences in the mean altitude deviation performance between groups were observed. In terms of performance, overall, it can be clearly seen that the mean deviation of GB was less than GA from the IGS, as GBs' median, upper and lower quartiles are closer to 0.

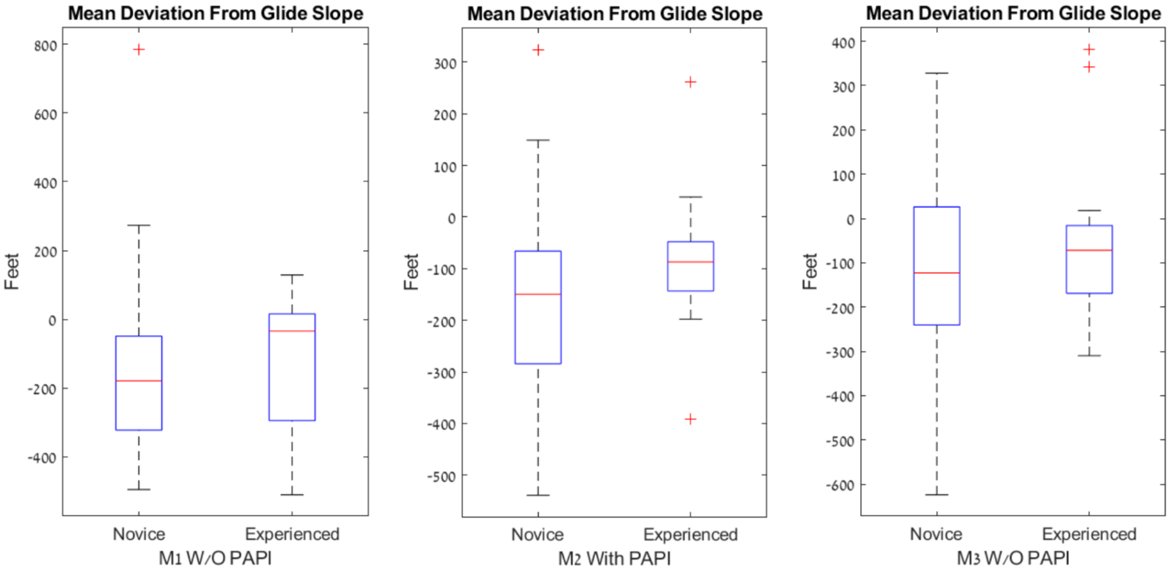

Figure 3.3: between-group mean boxplots comparison

3.2.2. Standard Deviation

Testing the pairs of values in terms of SD showed no statistically significant changes. Nevertheless, it is still important to note that GB were more precise, as their median, upper and lower quartiles are lower than GA. M1 and M3 of GA show 3 and 6 outliers respectively, which may indicate a negative tendency in precision, although as mentioned, their subject numbers are triple those of GB. The results are depicted in Figure 3.4.

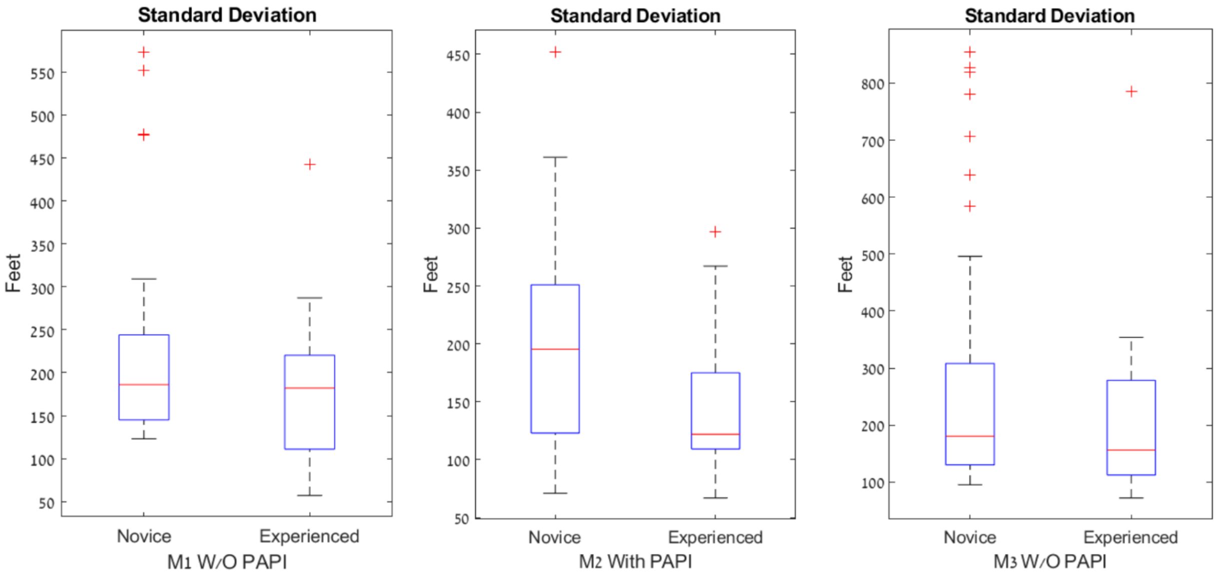

Figure 3.4: between-group SD boxplots comparison

3.2.3. Root Mean Square Error

In terms of accuracy, there is a statistically significant difference in medians of RMSE for GA and GB in the first measurement without (W/O) PAPI ($p = 0.0021$). Overall, GB shows better accuracy performance as their median, upper and lower quartiles are lower. The results are depicted in Figure 3.5.

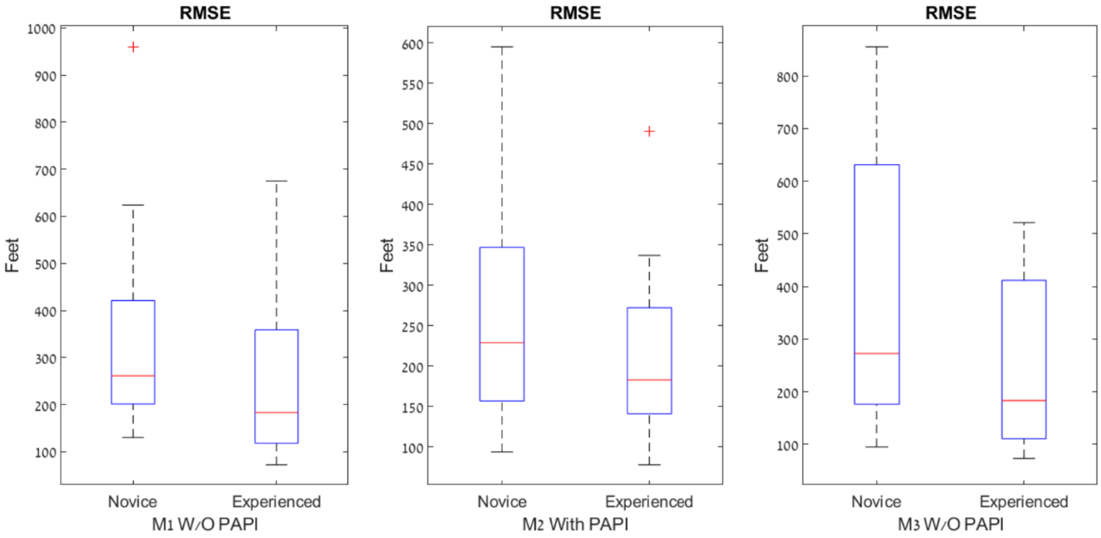

Figure 3.5: between-group RMSE boxplots comparison

3.2.4. Time spent below ideal glide slope

In terms of time spent below IGS, showed no statistically significant changes. However, GA had a stronger tendency to spend time below IGS, as their median, upper and lower quartiles are higher. The results are depicted in Figure 3.5.

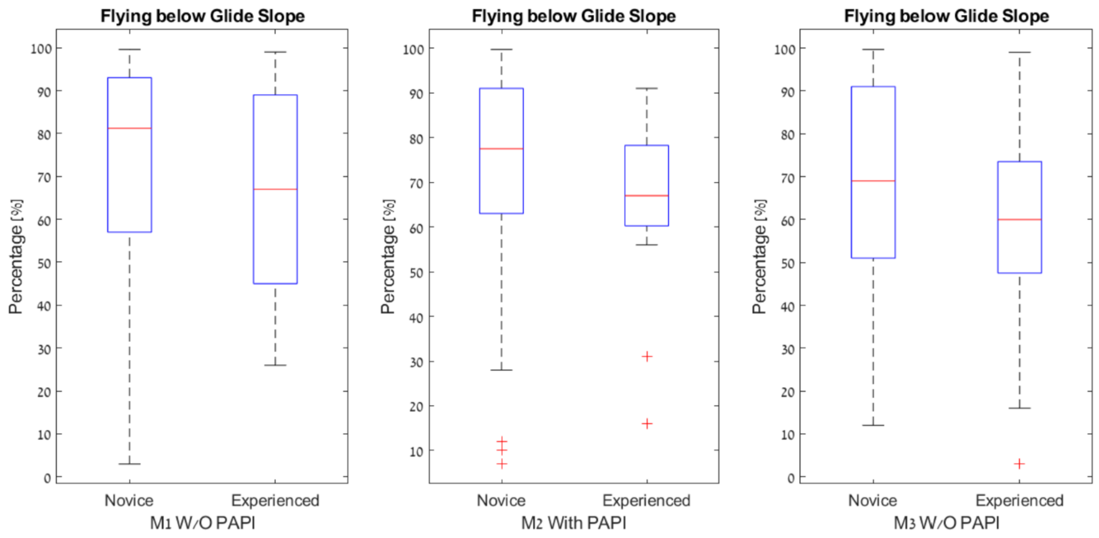

Figure 3.6: between-group time below IGS boxplots comparison

3.3. Summary comparison between groups

A pairwise comparison of the indices obtained returned the following results. No statistically significant differences were identified for both analyses within groups and between groups for all 4 indices involved, except the RMSE between GA and GB, in the first measurement W/O PAPI (P = 0.0472). The p-values obtained are provided in Table 2.

Table 2. Summary of p-values obtained for between-group indices

	p-Value		
Indices	**M1**	**M2**	**M3**
Mean	0.3585	0.062	0.4014
SD	0.1993	0.1223	0.2818
RMSE	0.0472	0.1669	0.0806
Time Below IGS	0.4588	0.1793	0.236

M1-3 - measurements; IGS - ideal glide slope;

Although there is almost no significant statistical difference, in order to present performance comparison trends between the groups, table 3 will be presented according to the medians of the indices results. The cells will note the group (“GA” or ”GB”) with the better performance in the specific parameter in each measurement.

Table 3. Summary comparison of performances between group A (GA) and group B (GB)

Indices	M1	M2	M3
Mean	GB	GB	GB
SD (Precision)	GB	GB	GB
RMSE (Accuracy)	GB	GB	GB
Time below IGS	GB	GB	GB

M1-3 - measurements; IGS - ideal glide slope;

Chapter 4 - Discussion

The aim of the thesis was to create an experiment with a BHI environment in a virtual reality simulator and to evaluate the differences in the performance of two groups of pilots in the descent plane, one experienced and the other novice. In this chapter, the results of the research and its methods will be discussed. A flight simulator setup allowed the participants to perform fully repeated test flights according to a two-variable flight profile with the necessary data retrieval. The first and third contained a BHI environment, while the second one was a night approach with PAPI. It helped to reflect performance progress both within and between groups when the measurements were taken in this particular sequence. It seems that the applied experimental set-up was mostly realistic and logical for the purposes and background of the current study, but nevertheless, the methodological tool choices were constrained by means of costs for the ability to perform the experiment with real airplanes in a real BHI environment, which would create the ultimate experience. Despite coming from different flight schools, having different commercial experiences primarily with different airplane manufacturers, and having different levels of flight experience, the participants and the groups formed appear to share a significant amount of commonality in terms of their abilities and are, therefore, comparable to a significant extent, especially given the pathfinding nature of the present study. The suggested methodology seems to be applicable. The four evaluated metrics of piloting performance—piloting accuracy, precision, mean deviation, and time below IGS—demonstrated some correlation among them and are unquestionably not in conflict with one another.

A thorough analysis of the obtained results showed some modifications and variations in the performance. However, a few additional factors must be taken into account with regard to the potential causes of any such performance variations before they can be evaluated and interpreted. The suspected generalized reason has thus been identified by the literature review. It is reasonable to separate a factor adaptation to the simulator itself - within the experimental setup used for the purposes of the current thesis. In fact, the vast majority of the volunteers who provided their optional feedback at the end, said that they did not think the transition had a positive influence on performance. However, some have criticized the VR environment used as contributing to the complexity since some adaptation was necessary. It's not surprising considering that none of the participants claimed to have used VR flight simulators before.

Regarding BHI environment comparison effects within the groups, there were no statistically significant differences between the three measurements. This means that the null hypothesis that there are no significant differences in performance between a night approach with or without the BHI environment was not rejected. These statements are supported by the results of the repeated-measures ANOVA. The three measurements in both groups show a propensity to frequently remain below the IGS and a mean height deviation that is below zero, indicating a concave approach and BHI. The fact that the group's performance did not change significantly during the second measurement can point to either good performance in M1 and M3, or BHI during M2. Due to the aforementioned experimental restrictions, the second is strengthened. These findings may point to consistent measurement techniques despite variable environmental factors. It should be noted that in the thorough examination of the box plots, it is possible to identify the effect of the BHI in the descent plane in relation to the PAPI measurement. The experienced group tended to stay longer under the IGS and was less accurate (RMSE) and stable (SD). Regarding the novice group, the only indication according to the box plots is the stability index (RMSE), due to the median and more precise limits of the measurement without BHI. Regarding the rest of the group's indicators, it can be seen that the third measurement, in which there is expected to be an improvement in performance, was the most scattered and had the largest ranges among the results of the group's subjects.

The results of the statistical analysis of the data between the groups showed that, with the exception of one, no significant differences were obtained for all parameters. Surprisingly, the results of the analysis do not disprove the hypothesis that there is a significant difference between experienced and novice pilots under BHI. These statements are supported by the results of the Wilcoxon rank-sum test. However, in line with the aforementioned hypothesis, in the detailed analysis of the data between the groups by using box plots with reference to the medians, it is possible to distinguish a performance advantage in favor of the experienced pilots in all parameters unanimously. In terms of accuracy (RMSE), the level of expertise was crucial. The experienced pilots were much more accurate according to the first measurement in which they were exposed to BHI. The first measurement is actually the indication to test an initial dealing with the illusion, which best reflects the pilot's performance in real-time. It's interesting to note that GA lessened the accuracy gap between M1 and M3 performance under BHI. This number grabs our attention because it shows a rapid improvement curve and can either represent the number of hours and training sessions required to achieve a sufficient level of performance or, alternatively, the level of performance of an experienced pilot.

The results support the BHI theory because there was a decisive tendency to go well below the IGS and create a concave approach and negative mean deviation, as mentioned in the art literature, which confirms the increase in the danger factor of the illusion. It is not possible to distinguish an improvement in the graph between the measurements, and sometimes it even diminishes some of them. This result reflects the ratio of performance versus the level of experience. This means that the level of experience here did not constitute a significant part, just as the level of experience in the third measurement did not show an improvement compared to the first. However, one should be careful with the assumption that experience does not play a significant role because the number of measurements in this experiment is relatively minimal. The results reinforce the claim of M. Chang [25] that BHI is an illusion that cannot be avoided no matter what your level of experience.

Chapter 5 - Conclusion

In the current thesis, the aim is to find out what changes occur in the descent plane during night approaches on the simulator in an environment typical for approach, through a black hole for novices and experienced pilots. Knowledge gaps in the subject matter of the field resulted from the issue not being subjected to a thorough review under the state of the art analysis. As other articles have noted, the topic was thus found to be understudied. The 53 pilots were divided into comparable groups of 15 experienced and 38 novice pilots, with the appropriate experimental methodology and setup being developed and then used. The experiment's goal was to observe the changes that take place during the transition between the various approaches and the impact of the aforementioned illusion. Participants were exposed to BHI during two-night approaches, M1 and M3, and the second-night approach, M2, without a BHI environment. The pilot's performance was evaluated by collecting and analyzing deviations from the necessary parameters. In response to the inquiry, "What changes occur in the descent plane during night approaches on the simulator in an environment typical of black hole approaches for novice and experienced pilots?" it was found that the BHI environment didn't significantly affect piloting performance. Therefore, it was necessary to reject the first hypothesis that the BHI was a significant factor. The second research question, “Is there within-group differences developments under BHI approaches?”, received a negative response: no statistically significant indicators suggest any levels of changes. It confirms the respective hypothesis of the black hole environment not being a factor in the issue of night approaches. Finally, “is there any difference in descent plane performance in black hole approaches between the groups?”, the present observations determined that there is an accuracy significant difference in the pilots’ first response to the BHI environment exposure. As a result, it was confirmed that the initial experience was a factor. In this way, both the main goal of the research as well as its auxiliary goals were accomplished.

Nevertheless, there were several limitations that the current thesis had to work within. The disadvantage of the VR setup is that the individuals have to become used to it, which could have affected the outcomes due to its novelty to the participants. The early use of flight simulators as a juvenile may also be a factor in the generational variations between the groups. Finally, the stress factor under which the pilot was given real flight time was flawed, which undoubtedly affected the pilot's performance. This is due to legitimate reasons of funding, efficiency, and time.

In order to decide in the most accurate way whether the subjects were exposed to an illusion compared to the other approaches, the subject had to make quite unconventional predictions in order to obtain significant differences. It was therefore challenging to draw attention to the differences between and within the groups. Based on these findings, adding stress receptors may be a more realistic indication in subsequent studies. And for even more thorough research, conducting this research in the real world may even produce more accurate results, allowing researchers to finally get around the challenge of having different habits from those of the simulator software. It was possible to see interesting results in the progress graph between the groups, but due to a too small sample, it is difficult to represent a reliable progress graph. A similar experiment with a higher number of measurements could add a practical training dimension.

The thesis nevertheless maintains the scientific evaluation despite its limitations. It alludes to earlier suggestions and is an extension of earlier trials. This is the only comprehensive article of its sort on how to assess both novice and experienced pilots' performance. In comparison to other research, it also offers a thorough examination of the flying characteristics in the descent plane. The current thesis continues to act as a guide for future studies in this area that might benefit from the knowledge gained here.

References

1. R. Gibb, R. Schvaneveldt, and R. Gray, “Visual misperception in aviation: Glide path performance in a black hole environment,” Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 50, no. 4, pp. 699–711, 2008.
2. CAE Oxford Aviation Academy. Human Performance and Limitations. KHL Printing What. Pte Ltd, UK, 2014.
3. “Night Visual Approaches | SKYbrary Aviation Safety.” *SKYbrary Aviation Safety*, skybrary.aero, 15 May 2021, 3.
4. Transport Canada. (2012, January 17). Hazards associated with flying at night - powerpoint presentation. Transport Canada. Retrieved July 29, 2022, from 4
5. R. Gibb, R. Schvaneveldt, and R. Gray, “Visual misperception in aviation: Glide path performance in a black hole environment,” Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 50, no. 4, pp. 699–711, 2008.
6. CAE Oxford Aviation Academy. Human Performance and Limitations. KHL Printing What. Pte Ltd, UK, 2014.
7. Federal Aviation Administration. Pilot's Handbook of Aeronautical Knowledge. USA, 20216
8. D. M. Jacobs, A. H. P. Morice, C. Camachon, and G. Montagne, “Eye position affects flight altitude in visual approach to landing independent of level of expertise of pilot,” PLOS ONE, vol. 13, no. 5, p. e0197585, 2018.
9. F.E. Robinson, H. Williams, D. Horning, A.T. Biggs A comparative evaluation of hypotheses to explain the black hole illusion
10. R. Gibb, R. Schvaneveldt, R. Gray Visual misperception in aviation: glide path performance in a black hole environment
11. J.J. Gibson The Perception of the Visual World Houghton Mifflin, Boston, USA (1950)
12. M.J. Sinai, T.L. Ooi, Z.J. He Terrain influences the accurate judgement of distance Nature, 395 (1998), pp.

13. M. Mulder, J.M. Pleijsant, H. van der Vaart, P. van Wieringen The effects of pictorial detail on the timing of the landing flare: results of a visual simulation experiment Int. J. Aviat. Psychol., 10 (3) (2000), pp. 291-315
14. G. Lintern, J.M. Koonce Display magnification for simulated landing approaches Int. J. Aviat. Psychol., 1 (1) (1991), pp. 59-72
15. T.L. Ooi, B. Wu, Z.J. He Perceptual space in the dark affected by the intrinsic bias of the visual system Perception, 35 (5) (2006), pp. 605-624
17. National Transportation Safety Board Aviation Accident Final Report (2017) Beech-65-A90-1, Slidell, Louisiana, April 19, 2016 (Aviation Accident Final Report No. CEN16FA158; p. 10).
18. J. Goh, D. Wiegmann Human factors analysis of accidents involving visual flight rules flight into adverse weather Aviat Space Environ. Med., 73 (2002), pp. 817-822
19. J. Kim, S.A. Palmisano, A. Ash, R.S. Allison Pilot gaze and glideslope control Trans. Appl. Percept., 7 (3) (2010)
20. “The Black Hole Illusion: A Neglected Source of Aviation Accidents ScienceDirect.” *The Black Hole Illusion: A Neglected Source of Aviation Accidents - ScienceDirect*, www.sciencedirect.com, 23 Nov. 2021, https://www.sciencedirect.com/science/article/pii/S0169814121001530?pes=vor#bib23.
21. R. Gibb, R. Gray Terrain orientation theory for a visual approach to landing Proc. Hum. Factors Ergon. Soc. Annu. Meet., 50 (16) (2006), pp. 1661-1665,
22. Federal Aviation Administration Airplane Flying Handbook (No. FAA-H-8083-38) (2016)
23. Federal Aviation Administration Pilot's Handbook Of Aeronautical Knowledge (No. FAA-H-8083-25b) (2016)
24. E.S. Calvert Visual judgments in motion J. Navig., 7 (3) (1954), pp. 233-251
25. M. Chang The Influence Mechanism of Space and Time Cues on the Black Hole Illusion during the Approach: The Selection and Training of Pilots for Carrier Aircraft (Doctoral Dissertation) Shaanxi Normal University, Xi’an, China (2013)

26. L.J. Kramer, R.E. Bailey, L.J. Prinzel III Commercial flight crew decision making during low-visibility approach operations using fused synthetic and enhanced vision systems Int. J. Aviat. Psychol., 19 (2) (2009), pp. 131-157
27. H.J.M. Pennings, E.A.P.B. Oprins, H. Wittenberg, M.M.J. Houben, E.L. Groen, E. Groen Spatial disorientation survey among military pilots Aerospace Med. Human Perform., 91 (1) (2020), pp. 4-10,
28. D.G. Newman An Overview of Spatial Disorientation as a Factor in Aviation Accidents and Incidents (Aviation Research and Analysis Report No. B2007/0063) Australian Transport Safety Bureau, Canberra City (2007)
29. S. Woods, S.R. Winter, S. Rice, S. Hampton, P. Craig The impact of motivation on continued VFR into IMC: another perspective to an on-going problem Collegiate Aviation Rev. Int., 38 (2) (2020)
30. Ming Chang, Lei Huang, Xuqun You, Pei Wang, Gregory Francis, Robert W. Proctor, The black hole illusion: A neglected source of aviation accidents, International Journal of Industrial Ergonomics, Volume 87, 2022
31. V. Socha, L. Karapetjan, J. Bořil, L. Hanáková, L. Socha, T. Havel Black Hole Approach: A Systematic Review. 2020 New Trends In Civil Aviation (NTCA), 117–121 (2020),
32. A.G. Shapiro, D. Todorovic (Eds.), The Oxford Compendium of Visual Illusions (illustrated ed.), Oxford University Press (2017)
33. F.E. Robinson, H. Williams, A.T. Biggs Preliminary support for the line bias illusion as a contributor to black hole effects Int. J. Aerospace Psychol., 30 (3–4) (2020), pp. 130-151,
34. S.M. Zlepko, L.G. Koval, D. Kh Shtofel, V.O. Homolinskyi, M.I. Palamarchuk Peculiarities of psycho-physiological selection of operators for unmanned aviation systems 2020 IEEE 15th International Conference On Advanced Trends In Radioelectronics, Telecommunications And Computer Engineering (TCSET), IEEE (2020), pp. 628-631,
35. 43Daily. “Pilot’s Eye View: Stunning Cockpit Video of Plane Landing over LA at Night Shows Perspective Passengers Never Have.” *Pilot’s Eye View: Stunning Cockpit Video of Plane Landing over LA at Night Shows Perspective Passengers Never Have*, www.dailymail.co.uk, 22 Mar. 2012,

https://www.dailymail.co.uk/news/article-2118992/Pilots-eye-view-Stunning-nighttime-video-plane-landing-LA-filmed-cockpit.html.

36. "Night Landing in a Mooney at Salt Lake City International Airport." YouTube, www.youtube.com, 27 May 2014, https://www.youtube.com/watch?v=dIQUCX2YIQk.
37. Gibb RW (2007). Visual spatial disorientation: Revisiting the black hole illusion. Aviation, Space, and Environmental Medicine, 78, 801–808.
38. Samuels, M. L., Witmer, J. A., & Schaffner, A. (2012). Statistics for the Life Sciences (4th ed.) [E-book]. Pearson.
39. Davis, C. S. (2008). Statistical Methods for the Analysis of Repeated
40. Measurements [E-book]. Springer Publishing. https://doi.org/10.1007/b97287Lighting systems – precision approach path indicators (PAPI). Lighting Systems – Precision Approach Path Indicators (PAPI) | Federal Aviation Administration. (n.d.). Retrieved November 20, 2022

41. Lighting systems – precision approach path indicators (PAPI). Lighting Systems – Precision Approach Path Indicators (PAPI) | Federal Aviation Administration. (n.d.). Retrieved November 20, 2022

42. Aviator. (2022, April 18). How do papi lights work? aviation related posts, aviation pioneers and aviation accidents. Retrieved November 20, 2022

43. Gibb, R., & Gray, R. (2006). Terrain Orientation Theory for a Visual Approach to Landing. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50(16), 1661–1665.
44. Crash of a Beechcraft 65-A90-1 king air in Slidell: 2 killed. Crash of a Beechcraft 65-A90-1 King Air in Slidell: 2 killed | Bureau of Aircraft Accidents Archives. (n.d.). Retrieved November 20, 2022
45. Enhanced Vision Systems - Federal Aviation Administration. (n.d.). Retrieved November 20, 2022, from https://www.faa.gov/news/safety_briefing/2018/media/SE_Topic_18-01.pdf