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The effects of different types of HUDs on Cybersickness

Effects of Diegetic and Non-Diegetic displays on Cybersickness in Virtual Reality

Master's thesis in Game Design and Technology

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Department of Some Subject or Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Motion Sickness, or the more scientifically accurate term Cybersickness, is one of the major contributing factors that is hindering the VR industry from reaching and achieving its true success and appeal. There are studies that establish that the HUD do have an impact on Cybersickness. The aim of this thesis is to expand upon this and study the effects of Cybersickness, with different types of HUD is to use these two different types of HUD. The two different types of display elements are Diegetic and Non-Diegetic heads up display (HUDs). A virtual reality flying game was created where the player could switch between the two design elements while flying. By switching between the different types of HUD, it can be used as a comparison to decipher if the effects of Cybersickness do vary and what guidelines can be drawn from it. Based on the results there does exist a difference in Cybersickness experienced with each type of HUD, with the Diegetic HUD being the preferred one along with it emerged a set of considerations when using either a Diegetic or Non-deigetic HUD for games.

Keywords: VR, Virtual Reality, HUDs, Diegetic, Non-Diegetc, Heads Up Display.

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Name Muhammad Ashar Imtiaz, Gothenburg, May 2020

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1 Introduction

The video game industry is more then a $100 billion global industry[18]. It is estimated that almost two thirds of American households contain individuals who regularly engage with and play video games[19]. Video games have been a veteran of the entertainment industry for quite some time now and span a multitude of technologies from arcade systems[20], consoles[21], handheld devices[22], mobile devices[23], etc. to name a few. A relatively contemporary technology that is slowly starting to make its mark in the gaming industry is Virtual Reality (VR). Within this technology all the user perceived information is purely artificial. To help visualize this information, VR hardware normally consists of some headset capable of displaying VR, and is further extended with more gadgets, such as controllers and infrared cameras to make the VR experience more immersive and interactive. The VR industry that is working with games is a comparatively new one but one that has gradually been gaining traction.However, on its way the technology has been plagued by a wide multitude of problems. One of its most prominent problems is the inducing of motion sickness while playing games, more commonly referred to as Cybersickness. While various work has been done to study and combat cybersickness based on the sensory conflict theory[24], the aim of this thesis is to study these phenomena from a different perspective. Nikolas Burkes in his study[25] validates that the presence of HUDs effect certain symptoms of cybersickness. The aim of this study is to expand upon this research and study the effects of cybersickness with different types of HUD display items: Diegetic and Non-diegetic.

1.1 History of Games

Ever since the advent of games, the gaming industry has been striving for an ever growing need for immersion to satisfy the appetite of the players. In 1962, Steve Russel introduced to the world the first digital video game: Spacewar![26]. Since its inception a domino effect has been created which has resulted in the development and creation of technologies and games aimed at providing an increasing experience of immersion in video games. Following Spacewars the world witnessed the birth of the first gaming home console "Odyssey" in 1972 created by Ralph Baer[27] as illustrated in **??**. One of Odyssey's games was the inspiration for Atari's Pong which would introduce to the world the first arcade video game. Following trough the years as the technology and the industry upgraded Nintendo[28] publicized and popularized the usage of handheld gaming devices with the release of its 8-bit Game Boy video game device in 1989[29]. Jumping forward in time to the modern age of

Figure 1.1: MIT student Steve Russell invents Spacewar!, the first computer-based video game. Over the following decade, the game spreads to computers across the country.[1]

gaming consoles, the market is being dominated by three major companies. Sony, Microsoft and Nintendo[30]. Each company have their own respective dedicated gaming consoles. Sony has Playstation[31], Microsoft has Xbox[32] and Nintendo recently released is trademark and hugely successful product the Switch[33]. All of these companies are continuously investing in revamping their consoles to stay ahead of the curve. However, recently Sony, Microsoft, Google and Valve currently have their sights set on virtual reality gaming[34], a technology that has the potential to change the way players experience video games. [35]

1.2 Virtual reality Games

Pushing the boundaries of creating even more immersive experience has led to the origination of virtual reality games. This growing industry offers a massive opportunity for brands due to the unique, memorable and highly engaging experiences it creates.[36]

What is virtual reality (VR)? The definition of virtual is "almost as if", which means that the term virtual reality basically means "almost as reality". So the term "virtual reality" pertains to 'near-reality'. It usually refers to a specific type of reality emulation. We gain knowledge of the world around us and get acquainted with it through our senses and perception systems. Humans are comprised of five senses: taste, touch, smell, sight and hearing. These are however only our most obvious sense organs. In reality humans possess many more senses than these, such as a sense of balance for example. These other sensory inputs, plus some special processing of sensory information by our brains ensures that we have a rich flow of information from the environment to our minds. Every piece of information that we acquire about our reality comes by way of our senses. Our entire experience of reality is simply a combination of sensory information and our brains sense making mechanisms for that information. It stands to reason then, that if you can present your senses with made-up information, your perception of reality would also change in response to it. You would be presented with a version of reality that is not really there, but from your perspective it would be perceived as real. Something we would refer to as a virtual reality.[37]

Figure 1.2: Playstation VR headset developed by Sony which can be played by plugging in the headset to the Playstation console.[2]

Within the domain of gaming, VR provides additional immersion as it tricks the brain into visualizing that it is actually in the virtual environment. This is what is called "presence" and is one of the major allures of virtual reality. In addition to appealing to our sense of sight and hearing, our sense of movement, balance and body awareness is also affected. All these sensory clues heighten the emotional link with the experience, thereby heightening our memory of it. Virtual reality is so powerful it's even been used to help paraplegics walk again.[36]

1.3 Cybersickness

The most major and common issues associated with virtual reality is Cybersickness and is one of the major contributing factors that is hindering the virtual reality industry from reaching and achieving its true potential and appeal. Cybersickness also known as virtual reality sickness is the nausea and discomfort caused by using virtual reality technology. The leading theory behind Cbersickness is based on the idea of sensory conflict. Essentially, the information received by your eyes in virtual reality does not always match up with what your body feels is going on in terms of balance and spatial orientation. Cybersickness can last for hours after participating

Figure 1.3: Symptoms of cybersickness.[3]

in virtual reality applications.[38]

Various work has already been conducted in order to combat and lower the effects of this issue. One suggested solution from the study conducted in order to combat cybersickness is an illusion, called ”vection”. Basically, it is the illusion of self-motion when actual physical movement is absent. “Vection” may be reduced with the help of many techniques which include reducing the speed of the player’s motion and reducing the complexity of textures. Another suggested solution within this field is reducing acceleration. It has been found that reducing accelerations can also effect cybersickness. The inner ear can detect changes in accelerations, but it doesn’t detect constant velocity. Another interesting approach to combat this issue is by the visualization of the movement’s trajectory. With visualizing the direction of motion it becomes more predictable to the brain, and the symptoms of virtual reality motion sickness are reduced.[39]

1.4 Aim of the study

Mentioned briefly above are several of the approaches that have been introduced to counter and reduce the effects of cybersickness. Another interesting approach that was undertaken by Nikolas Burkes[25] was to study if the presence of Heads Up Displays (HUD) had any effect on cybersickness. Based on his result, it has been found that HUD can reduce certain symptoms of cybersickness. For this study I thought it would be interesting to extend this study and observe the effects with diegetic and non-diegetic HUD. The basis for my proposal is to surround or place the player in an environment similar to that of a cockpit/cabin of a plane along with the different types of HUD[40]. The different types of HUD for this study include the diegetic and non-diegetic HUD. A diegetic HUD is a display element that exists within the fiction or context of the particular game. While non-diegetic HUD are the display elements that exist outside of the fiction of the gaming world and are only visible to the player. The intention is to surround the players with a static environment so that they can focus on that and either the diegetic or non-diegtic

HUD during continuous movement/flight. A similar example of this would be from the game Hawken[41] that incorporates both types of HUD at the same time as illustrated in 1.4.

Figure 1.4: A screenshot of the player's view from the cockpit from the game Hawken.[4]

The intention is to allow the users to switch between the different types of HUD while in flight and use the observations from the comparisons to study the effects of cybersickness within the two different environments. These observations can be used to deduce if either one of the two types of HUD has more effect on Cybersickness. My personal experience in the area has pointed out some difference in effects by playing games with similar environments such as Eve Valkyrie[42] and Until Dawn: Rush of Blood[43]. Additionally the observations and sentiments from the test users a set of considerations can be established to better educate the game designers regarding the potential consequences of using different types of HUD in virtual reality games.

Hence this leads to the following research question:

Which guidelines can be drawn from the potential varying effects on Cybersickness with the presence of non-diegetic and/or diegetic HUD displays?

2

Background

The unique appeal VR offers is attracting major businesses to meld VR with their marketing strategies. In the last recent years, the growth of virtual reality has gained major traction and can already be seen in major sectors, including education, military, video games, live events, real estate, healthcare and many more.[44]

2.1 Sensory Conflict Theory

2.1.1 Introduction

Especially in the world of gaming, VR has stood out and provided the consumers with an improved user experience. VR is considered one of the most intriguing topics in gaming trends, and has managed to grab the attention of the potential market. It was estimated that global revenues of virtual reality in the gaming industry were $4.3 billion in 2015[45]. The market size of the virtual reality games industry is pacing with a fast growth rate. It has the potential to boost the revenue of businesses in the gaming industry and is poised to be the 'next big thing' in the gaming industry. However, it is not quite there yet. Using VR makes some of its users sick. That sickness is caled Cybersickness: a type of sickness where the users develop symptoms similar to those in motion sickness. Since the recent emergence of an abundant number of consumer virtual reality headsets (Occulus Rift[46], PSVR[47], HTC Vive[48]) there has been a dramatic increase in both mass media and research publications that confirmed the provocative liability of the technology. The most widely accepted cause and theory for the origin of this sickness is the sensory conflict theory[49]. This theory states that the symptoms of the conditions are elicited from conflicting signals received from the visual and vestibular senses. The vestibular sense of humans aid to our ability to maintain balance and body posture. The vestibular organs are fluid-filled and have hair cells, similar to the ones found in the auditory system, which respond to movement of the head and gravitational forces. When these hair cells are stimulated, they send signals to the brain via the vestibular nerve.[50].

2.1.2 Independent Visual Background

One strategy based on the sensory conflict theory was presented by Duh, Parker and Furness[51] in their work, their strategy was to superimpose an independent visual background (IVB) to the simulation scene. An IVB is a visual scene component that provides visual motion and orientation cues that match those from the vestibular

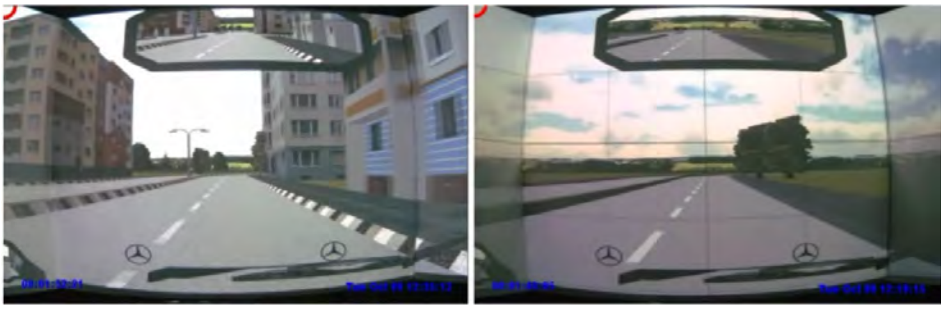

Figure 2.1: On the left side is the image containing high optimal flow and on the right is the one with less optimal flow.[5]

receptors. In their study, a mesh-like IVB was incorporated to the virtual environment in a driving simulator in an attempt to reduce simulator sickness. Their results indicate that simulator sickness was reduced due to the presence of the IVB.

In another, similar study conducted by Jäger at al.[5], they utilized the use of an IVB onto a virtual environment. However, the use of IVBs was one of several methods in the study. To counter simulator sickness they had set up three different methods:

- In the first method the virtual scene was optimized by reducing the optical flow. Optical flow depends on the virtual environment and objects such as building and trees close to the road generate more optical flow. Therefore, objects along the road (i.e., houses, street lamps) were removed and road side and surface were homogenized as illustrated in 2.1.

- In the second method, a black grid IVB was superimposed over the entire virtual scene.

- In the third method, Third, brightness of the lateral projection screens was decreased by 48 % to further reduce optical flow.

Twenty (10 women, 10 men) healthy participants took part in this study. None of the participants involved were taking any medication, nor suffered from any vestibular dysfunction. The mean age was 27.7 years. The results of their combined strategy and tests deduce that with their efforts they did reduce and lower the symptoms of simulator sickness.

2.2 Heads Up Display (HUD)

2.2.1 Introduction

The User Interface (UI) or Heads Up Display (HUD) are one of the most important and salient features of game development. With the aids of the HUD the players can interact with the game and receive a response in return. A game equipped with a compelling story, innovative and well implemented mechanics but burdened by substandard UI or HUD will not produce the desired results for a game to succeed.

The HUD not only supplement the user with vital information about the character and the game world status but often shapes the player behaviour as well.

The history of HUD in video games can be traced back to 1972 in the game Pong, one of the first games to incorporate HUD[6]. The game was basically two players playing tennis against each other. The developers realized that to induce more competitiveness amongst the players they needed to add players scores. Since its inception the necessity to display the remaining player lives, high scores and collectibles were utilized by games such as Space Invaders[52], Pac-Man[53], Sonic[54] and Super Mario[55]. As the years progressed and games became more complicated, HUD became an integral part to the genre of strategy and role playing games such as Final Fantasy[56], Warcraft[57] or Diablo[58].

With the swift advancement in 3d graphics in the 1990's the world was introduced to the 'first person' point of view (POV) gameplay, which created new challenges for HUD as then both the games and the HUD items were in the same 2d plane. Developers started realizing that HUD needed to be categorized under two branches: Non-Diegetic, which are basically HUD items on top of the game, and Diegetic, which are the display items that exist in a game world instead of being overlaid. More details on these two classifications are provided in later section 3.1.[59]

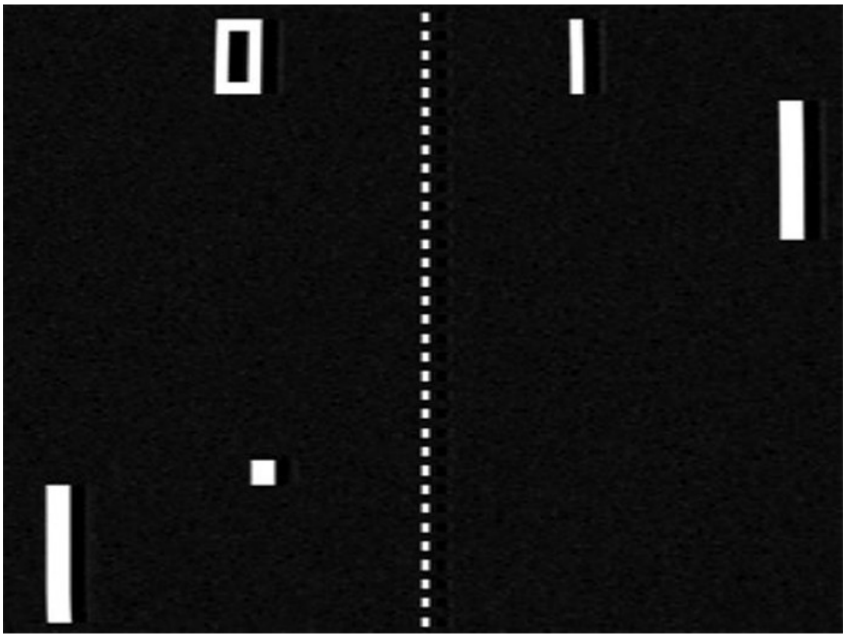

Figure 2.2: One of the earliest examples of HUD in the game Pong.[6]

2.2.2 Heads Up Displays (HUD)

Moving to the domain of HUD (Heads up displays), a study was conducted by Burks[25] to study the effects of HUD presence on cybersickness. In this study a HUD was overlayed onto a virtual environment in such a way that it did not disrupt the user experience. This was achieved by varying the presence of the HUD in proportion to perceive motion. From the results of the study it was observed that presence of HUD did reduce the feeling of cybersickness, with dynamic HUD reducing the symptoms more than the minimal presence of HUD in the scene. In this context the minimal presence and dynamic nature of the HUD refer to the transparency of the HUD elements. The threshold for minimum presence was determined to be 0.5 or 50% transparency.

Mentioned above are several studies conducted based on the sensory conflict theory. The intention of this thesis is to create an experience from the first person perspective, research was also conducted on HUD from the first person perspective in games. In a study conducted by Caroux and Isbister[11], the authors conducted two experiments to determine what characteristics of HUD influence the user experience in first person shooter and real time strategy games. In the first experiment, eye tracking and interviews were used to understand how and to what extent the players use and experience HUD in the different type of genres of games. This also unveiled the particular HUD characteristics that have a more significant effect on the player experience. In the second experiment the characteristics uncovered from the first experiment were utilized to study more in depth the influence of HUD design choices on player experience. Based on the results of the experiments in regards to the first person game, it was found that the primary use HUD were preferred to be placed on the top middle part of the screen. For the secondary use HUD they were preferred to be situated to the right hand and middle part of the screen in contrast with the the main HUD being situated in the top middle part of the screen.

In a similar study conducted by Peacocke et al.[7], the authors conducted a study to find the effectiveness of both diegetic (in game) and HUD options. With diegetic displays, game status information is conveyed using an in-game method rather than on the HUD[9]. In the experiment performed, different types of ammunition display methods were compared and analyzed for FPS (first person shooter) games. Theses different types of displays included various types of diegetic displays and HUD. Results from this study indicated that the diegetic "number-in-game" display performed best both in terms of reload time and shots taken between running out of ammunition and reloading. The different displays employed in the study are depicted in 2.3.

On the topic of involvement of diegetic elements in games a study was done by Iacovides, Cox, Kennedy, Cairns, Jenett[60], in which the influence and impact of diegetic components on the game component were observed. In this study two versions of a first person shooter game were examined by how much immersion is influenced by interacting with a diegetic and non-digetic interface. The game under investigation was Battlefield 3[61]. The first version (non-diegetic) contained the HUD and the other non-diegetic elements while the second version (diegetic) had these removed entirely in order to increase the realism of the game. Their finding unveiled that by the removal of non-diegetic components they were able to influence immersion in expert players, enhancing their cognitive involvement and sense of control. Cognitive involvement, in this context, entails items that measure effort

Figure 2.3: Overall gameplay (with bar on HUD ammunition display) and five conditions: (a) Bar-on-HUD (BH), (b) Number-on-HUD (NH), (c) Icons-on-HUD (IH), (d) Number-in-game (NG), (e) Icons-in-game (IG).[7]

and attention.

2.3 Formal Analysis of Eve Valkyrie

Formal analysis is a research method, where an artifact and its associated elements are scrutinized and analyzed closely. To further progress in the study I thought it was important to scrutinize in depth games of similar genre i.e. Eve Valkyrie[42]. More details regarding this method is provided in 4.1.

Eve Valkyrie[42] is a first person space shooter game for the virtual reality platform. During the game the player assumes the identity of an ace pilot and is tasked to fight against invading enemy forces. It is a rather straightforward and simple game and only the demo version available in the Playstation VR demo disk will be scrutinized.

Within the context of the demo, the following components are present during gameplay: *player spaceship*, *enemy spaceships*, *comrade spaceships*, *flak cannons* and *static turret guns*. These different types of spaceships are present for the full version of the game but for the demo there is one version. The game maintains a tab of your available *health bar* and *defence shield* and displays it in front of the player along with the *target crosshair*. The system actions in the game comprise of *spawn enemy spaceships*, *spawn comrade spacheships* and then commencing with *start a new level* after all the adversary units have been destroyed.

The setting of the player consists of the player situated in a seated position at the cockpit of their spaceship. The front screen of the cockpit is where the player can view the world in front of him for navigation. This front screen also contains the cross hair for aiming and HUD for the available *health bars* and *defence shields* diagonally across the front screen as illustrated in 2.4. The central console of the cockpit contains a minimap HUD[62] which reveals the location of the *enemy spacheships* and *comrade spaceships*. To the left and right of the central console there are HUD situated demonstrating the current *capacitors* and *velocity* of the player. Also situated to the left and right side of the cockpits are the *flak cannons* and *static turret guns* on each side.

Figure 2.4: An illustration of the HUD in Eve Valkyrie.[8]

Similar to other first person shooter games, player actions are initiated in response to the attacking enemy waves. The demo version of the game starts with the player taking off and given a short time to maneuver within the environment before the enemies start spawning. The basic enemy spaceship available in the demo version of the game is a component with a limited health value and the basic actions available to it are either *advance towards the player ship* or *advance towards your comrades ships* and when in firing range start *attacking*.

Players of Eve Valkyrie have a relatively few and limited actions at their disposal. These actions are just *tracking enemies*, *flying* towards the enemies and then try to *destroy* them. To aid the players with destroying the enemy waves of spaceships the players are equipped with *flak cannons* and *static turret guns*. The difference between the two weapons is that in order to use the flak cannon you need to *track the enemy* using the cross hair continuously for a short period of time. Once the target has been locked a seeking missile can be shot towards the enemy dealing considerable damage. Using the *static turret guns* the players can shoot a steady stream of ammunition in a straight line through the cross hair. In order to damage the enemy, though, the player would have to maneuver their aircraft so that it is aligned with the enemy ship. During the aerial combat, when the player is the one being attacked, they can use evasive maneuvers such as *speed boosts* or using *barrel rolls* to avoid the crosshairs of the enemy and being destroyed.

Component	Component Actions
Player Spaceship	Advance towards enemy spaceship, attack enemy spaceship, avoid incoming attack by enemy spaceship
Enemy Spaceship	Advance towards comrade or player ship, attack player or comrade ship, avoid attacks by player or comrade spaceships
Comrade Spaceships	Advance towards enemy spaceship, attack enemy spaceship, avoid incoming attack by enemy spaceship
Flak Cannon	Fire seeking missiles
Static Turret Guns	Fire regular ammunitions

Figure 2.5: Component actions in Eve Valkyrie

The demo version of the game ends when you are able to successfully destroy a few enemy ships within the available time. The goal of the player is to stay alive and destroy as much enemies as possible. An optimal goal of the player could be to destroy as many enemy ships as possible all the while also trying to prevent the player's comrades demise.

3

Theory

In this chapter knowledge is presented important to understand the difference between the differnt types of HUD which are the diegetic and non-diegetic HUD followed by different design frameworks.

3.1 Diegetic and Non-diegetic representations

HUD or Heads Up Displays have adopted their name from the display technology used to project flight information onto the windshields of modern aircraft. HUD has been around since the inception of video games; displaying important game information such as score, level progression, character health and equipped items amongst others.[63]

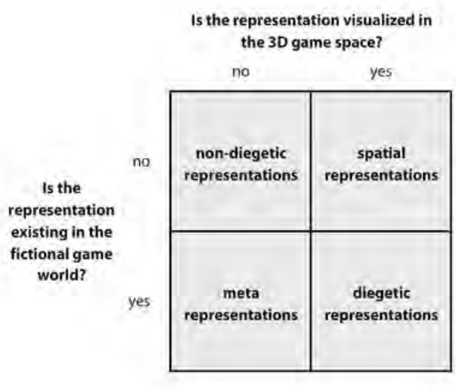

Figure 3.1: Design Space of User Interfaces.[9]

Interface design differs between different genres of games. As demonstrated by Caroux and Isbister[11], the placement of HUD varies since the information required and perceived by the players are different since the goals and aim of the game differs. Illustrated in 3.2, shows the placement of HUD for a first person shooter game and a real time strategy game[64]. On the contrary, there are certain games that are entirely stripped of a HUD in an attempt to increase player immersion for e.g. Journey[65]. However, in most cases of games regardless of genre the presence of HUD is a common aspect. To avoid players being distracted from the gameplay, HUDs are often designed to replicate the game's context as illustrated in 3.3.

Figure 3.3: HUDs incorporated in the game Motoracer 2 specific to the game's context.[10]

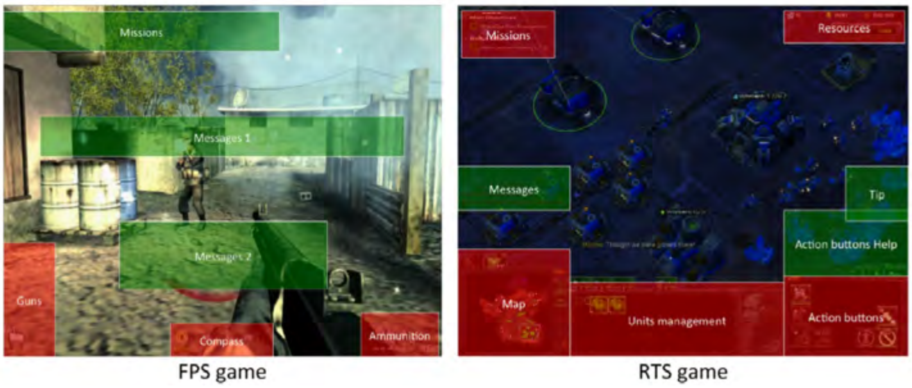

Figure 3.2: Screenshots of the games used in the study by Caroux and Isbister. Red boxes represent information permanently for both genres and the green boxes represent information that is displayed occasionally.[11]

Designing HUD for a video game can be approached from a variety of methods. User interface elements can either be comprised of spatial or fictional properties. Spatial elements exist within the game design space, while fictional elements are representations of artifacts that exist within the game's literature[9]. As illustrated in 3.6 by Fagerholt and Lorentzon[9], all information presented to the player falls within one or more categories. What they deciphered was that a natural starting point for charting the design space was to divide it into two dimensions: diegesis (is the UI element diegetic or not?) and spatiality (does the UI element exist within the 3D game space or not?). To facilitate their study they utilize a four field chart to distinguish between the different display items (3.6). Non-diegetic elements are those elements that fall outside of the of the scope of the game space and do not concede with the game characters. These elements are seen to overlay the game world, such as health bars or even background music. Non-diegetic interfaces are explicit interfaces that usually convey health and/or ammo count to the player utilizing bars and/or texts. An example of such a HUD is displayed in 3.4.

Figure 3.4: *Far Cry: Primal* is an example of non diegetic display items.[12]

Figure 3.5: *Dead Space* displays the health meter (blue bar mounted on player's back).[13]

Meta-representations are elements that correspond to the game's fiction or narration, but are represented outside of the game space. Such games attempt to present the information that match the context of the game world, so a game may present a navigational menu that is similar to a device in the game's fiction, but is outside of the game space. A meta-perception is a combination of non-diegetic and meta-representation elements. Blood splatters or red color filters, overlaid on the screen when a character is injured, is not part of the game space, but tries to portray a game status perception in a visualized manner. Spatial representations are geometric elements seen within the game space, but are not represented within the game's fiction. For example, an object, such as a treasure chest, may be outlined or glowing to present importance. Although the chest is within the game space, the outline indicator is not part of the game's fiction or environment.[66]

3.2 Game Design Patterns

Game Design patterns are models that support the design, analysis and comparison of games. They are the description of recurring instances of actions that take place over a variety of games instead of being limited to and confined to just one game. More specifically, a pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice. For the purpose of the game creation within this thesis, game design patterns can be used. It will be a method which would benefit identifying the patterns with games of similar intended genres that provide the best experiences and then combine them into the game idea to create an enjoyable and immersive experience.

Game design patterns have been designed and concocted to aid the process of creative design[67]. Each pattern identified is usually associated with most of the characteristics mentioned below:

- **Name**: The behavior identified within the game should be represented by short, specific and idiomatic names. The purpose for this is to provide mnemonic support after the pattern description has been read.

- **Description**: This characteristic provides more detail of the behavior identified within the gameplay. It also includes a narration of how it affects the structural framework.

- **Consequence**: This section educates the designer the pros and cons of integrating the corresponding behavior of the pattern.

- **Using the pattern:** This section is used to mention the common choices a designer is faced with when applying a pattern, often exemplified by specific game elements from published games.

- **Relations**: This section states the relationship between similar design patterns. There are three types of relationships: *superior patterns, subpatterns and conflicting patterns.*[67]

3.3 Game Mechanics

Game mechanics are methods invoked by agents, designed for interaction with the game state. According to Järvinen[68], mechanics are a means to guide the player into particular behaviour by constraining the space of possible plans to attain goals. Within these conditions, game mechanics are best described with verbs. For example considering a game of a similar genre to the purpose of this study: F-22 Raptor[69] from which the following mechanics can be deduced: **flying**, **firing weapons**, **rolling** and **straffing**. All of these are methods for agency within the game world, actions the player can take within the space of possibility created by the rules.[70]

3.4 MDA Framework

Mechanics, Dynamics and Asthetics (MDA) is a framework developed by Hunicke, LeBlanc, Zubek[71], and the aim of this framework is to aid and strengthen the iterative process of developers, scholars and researchers making the study of game design to be conducted more effortlessly.

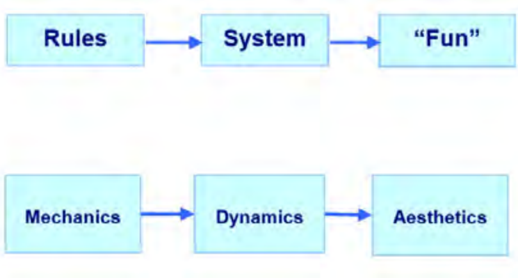

Figure 3.6: The MDA framework

Games are created by designers to be played and experienced by the players similar to other forms of media. However, there is a considerable difference between traditional media (for e.g. TV shows, movies etc.) and games pertaining to the way they are ingested. The way games are consumed and perceived by players is quite unpredictable. Based on this the MDA framework distributes the consumption of the games into the following three components:

- **Mechanics**: According to the study of Hunicke, LeBlanc, Zubek[71], mechanics are the various actions, activities or options allowed to the player which they can execute within the context of the game.

  For example when we are talking about games which involve a deck of cards, the common game mechanics according to the definition of Hunicke, LeBlanc and Zubek that usually emerge are **playing a card**, **removing a card** or **shuffling the deck**. This in turn leads to the emergence of dynamics such as bluffing. Similarly taking the genre of the intended the intended game of this thesis: A first person shooter flying game, the basic mechanics included are weapons, ammunition and spawn points which can produce dynamics such as aerial combat.

- **Dynamics**: The mechanics support the dynamics of the game. The dynamic component of the model describes the run time behaviour of the mechanics being applied. Dynamics work on creating and illustrating the intended experiences.

  For example in order to create, *Challenge* rules must be in place that encourage and nurture components such as *Combat*[72] and *Time Pressure*[73]. Similarly in order to fabricate *Team Development*[74] rules must be in place that either allow information to be shared amongst different parties and winning objectives that might be hard to achieve if playing alone. All of the italicized words mentioned in this paragraphs are game design patterns as discussed in section 3.2.

- **Aesthetics**: The aesthetic component of the model of this framework describes how enjoyable and fun the games are played. The terms 'enjoyable' and 'fun' are too vague to be interpreted. According to the Merriam-Webster dictionary, the definition of aesthetic is a branch of philosophy dealing with the nature of beauty, art, and taste and with the creation and appreciation of beauty[75]. However, the need is there for more defined and refined terminology which would help all the parties involved to perceive what aspects of the game contribute towards making it an enjoyable and fun experience.

  For further illustration an example with two games of similar genre to this study and their associated aesthetics are listed down:

  - **Eve: Valkyrie (Multiplayer mode)**: Fellowship, Expression, Challenge.
  - **F-22 Raptor**: Challenge, Sensation, Competition, Narrative.

  As demonstrated from the examples above in my opinion the multiplayer mode of Eve: Valkyrie[76] is more inclined towards Fellowship rather then Challenge where as in the case of F-22 Raptor[69] it is vice versa as it is more based towards you as a singular player against multiple enemies. Utilizing this we can create and define aesthetic models for the games mentioned above. Considering the same examples of the games mentioned above we can interpret that both games are competitive in nature. The games terminates when one player (in the case of F-22 Raptor) or team (in the case of multiplayer mode of Eve: Valkyire) defeats the other team/enemies. For competitive games it is important to incorporate adversaries and a clear winning condition in order for the game to succeed and for its players to enjoy.

4
Methods

This chapter is concerned with the methods incorporated within the study of this thesis. The final aim of this study is to be able to generate some guidlines regarding the use of particular HUDs in VR. To achieve this a game was to be constructed through which the effects of different types of HUDs can be observed. To construct this game the methods mentioned in this chapter have been used.

4.1 Formal Analysis

Formal analysis is a qualitative research method where an artifact and its associated elements are scrutinized and analyzed closely. In the context of games, formal analysis of gameplay is used to study games. In this method games are studied independent of context.[77]

In order to be able to answer the research question, I aim to construct a game centered around the research question. To acheive this purpose an analysis of games and genres that share a similar idea will be analyzed. Through this analysis a clearer path towards the final game creation can be better realized. Time is the most limited resource for the purposes of this prototype development. As such the qualitative approach will be preferred moving forward and is the reason why this method has been chosen to be used.

For this study I played the demo version of the game Eve Valkyrie[42] available on PSVR on the demo disk. The demo of the game is not a complete version and consists of a short time of gameplay where you have the chance to sit in the cockpit of the jet where you can check your surroundings, fly in the world and engage in a dash of dog fight. The demo, albiet short in length and features, should cover the most relevant aspects i.e. the HUD and the flight experience, for the purposes of this thesis. More details regarding the evaluation of this game can be found in 2.3.

4.2 Iterative Process

For the actual intended game visualization and creation for this thesis I planned to utilize the iterative process as exhibited by Tracy Fullerton in the book Game Design and Workshop[78]. The iterative process or "iteration" is a method of designing, testing and evaluating for improvement. This process is repeated until player satisfaction has been achieved.

The iterative process consists of the following steps:

- **Step 1: Brainstorming**:
  - Decide the intended player experience which in the case of this thesis is the sensation of flying in an aircraft.

  - Come up with game mechanics that would help attain the required experience

  - Conjure up a number of ideas (at least 3).
    Write short descriptions for each of the ideas, which is called a concept document.
    Test your concepts with potential players and see which one ranks the best.

  Step 2: Physical Prototypes
  - Create paper prototypes of the concept of the game that has been finalized in the process above. For this study paper prototypes would benefit the design of the cockpit and the diegtic and non-diegetic displays.

  - Another interesting approach that can be undertaken to utilize the technology of virtual reality would be to use virtual reality sketching tools to create prototypes.

  - Once the design/gameplay has been finalized and demonstrated that it works, a document describing how the game functions is written.

  Step3: Software Prototypes
  - When the prototyping step has been concluded the process moves onto creating software prototypes. In this scenario this is where the low fidelity version of the intended game would be created using a game engine.

  - Testing the digital prototype.

  - When the prototype demonstrates that it can achieve the intended player experience, plans can then be developed in order to move towards high fidelity prototypes.

  Step 4: Design Documentation
  - In this scenario the design documentation step will be comprised of the creation and regular update of a development diary and notes that will ultimately be used and incorporated towards the final report of the thesis.

There are two more remaining steps to this process: *Production* and *Quality Assur-*

ance. The reason I am excluding these steps is the steps included serve the purpose of this study and the excluded steps are more in connection with creating a full fledged game.

4.3 Prototypes

To help and assist in visualizing the idea thought up of in the brainstorming session the assistance of prototypes was used.

A prototype is a preliminary specimen or sample used to constitute a system design. Prototypes can be assembled from something simple such as paper to something sophisticated as a software. In the domain of Interaction Design it is easy to mingle the concepts of sketches and early simple prototypes. But there is one important distinction that differentiates between the two. The prototype must be "interactable", something should occur as a result of performing some action on the prototype. There are two kinds of prototyping.[79]

4.3.1 Hi-fi Prototypes

Hi-fi prototypes are similar visually and in feeling, if not necessarily in regards to functionality, to the envisioned final product. They are usually produced in software, using the development environment to create and allow interactive effects to be mocked-up easily. The advantages that this kind of prototype possesses is that it is practical for the assessment of main design elements. It allows for more realistic and productive data to be retrieved. This type of prototype forces the designer to think about the design elements to a much greater degree than just paper specs and helps to keep focus on the user interaction.

However, it is also saddled by some problems. The most glaring of which, is that is the sense of realism it can portray to the end users and stakeholders that this is what the final product would represent. This could be dangerous if the designer has not checked the details and went trough the ideas thoroughly beforehand. Finally, I believe that another possible issue is the requirement of additional time and certain expertise when compared to the other types.

4.3.2 Low-fi Prototypes

These prototypes often referred to as paper prototypes or sketches, possess less realism when compared with hi-fi. They adhere more towards the broader and general design ideas such as content, structure, tone etc. The advantages this kind has over hi-fi is that they can be constructed more quickly and do not require any form of expertise generally. They capture the premature design thinking and should aid the process of generating and evaluating many different possible design solutions.

Some shortcomings that this kind of prototyping comes with, is that it is limited only by your imagination, time and available materials. Another limitation I believe

TABLE 1
Symptoms in MSQ and SSQ

MSQ Symptom	*Retained for SSQ*	*Eliminated for SSQ*
General discomfort	X	
Fatigue	X	
Boredom		X
Drowsiness		X
Headache	X	
Eyestrain	X	
Difficulty focusing	X	
Increased salivation	X	
Decreased salivation		X
Sweating	X	
Nausea	X	
Difficulty concentrating	X	
Depression		X
Fullness of head	X	
Blurred vision	X	
Dizziness (eyes open)	X	
Dizziness (eyes closed)	X	
Vertigo	X	
Visual flashbacks		X
Faintness		X
Awareness of breathing		X
Stomach awareness	X	
Decreased appetite		X
Increased appetite		X
Desire to move bowels		X
Confusion		X
Burping	X	
Vomiting		X

Figure 4.1: Symptoms of MSQ and SSQ.[14]

is the amount of information that can be relayed to the users and stakeholders.

4.4 Sketches

Sketches and prototypes are both different processes which facilitate the activity of envisioning an idea and conveying them to others. By definition, a sketch is a quick and rough drawing that gives a brief overview of the idea at hand. Sketching is a swift freehand drawing that is not usually intended as a finished product but is a great method as it allows designers to quickly visualize and convey multiple design concepts.[80]

4.5 Simulator Sickness Questionnaire

At the beginning of the playtest session of the prototype, the players will be asked to play the game in both modes of HUD (diegetic and non-diegetic). Based on their experience they will be issued an Simulator Sickness Questionnaire (SSQ). This questionnaire was derived from the Pensacola Motion Sickness Questionnaire (MSQ) by Kellogg, Kennedy, Tolhurst and Graybiel in 1965[14]. The MSQ had several deficiencies for calculating or measuring Simulator Sickness (SS). Several symptoms comprised of scoring the MS are not suitable for measuring SS and can be misleading as illustrated in figure 4.1. These drawbacks led to Kennedy, Lane, Berbaum and Liliennthal to the development towards a new questionnaire which was more straight forward and was equipped with more capability to measure symptoms of of both simulator sickness and cybersickness.

The SSQ's questions are presented in the form of the symptoms experienced during the playthrough or experience. The users rank their experience by selecting from the following options available: *None, Slight, Moderate, Severe*. These choices made by the players could be used to distinguish the amount of Cybersickness observed with each type of HUD and then be used to see how much of a difference exists between the two types. The symptoms have been shown in B

4.6 Surveys

In order to assess whether the test users observed any difference in cybersickness with the different types of HUD, the creation and usage of surveys is planned.

One of the primary objectives of Games User Research (GUR)[81] is to analyze the interaction between players and games with the intention of using these observations and results to either improve the experience of the players or to study a certain aspect of the corresponding experience. The surveys are a quick, simple and cost effective method for gathering player's opinions and gaming habits. Surveys can delivered to the potential users via a multitude of ways for e.g. email, telephone, in person etc. This method has been a recurring and consistent, in the domains of psychology, marketing and Human Computer Interaction (HCI) to help answer a variety of questions.[82]

Surveys in GUR can be used to analyze the following components:

- **Player attitude and experiences**: The surveys can be used to gather precise measurements and represent the feelings and perceptions of a certain population. Since this thesis is opting towards a qualitative approach, surveys can be utilized to understand player's interaction with a game.

- **Motives**: Surveys can be used to garner the player's motives. This can be used to reveal the reason why player's make certain choices in different situations.

- **Player Characterisitcs**:Surveys can be used to figure out and discern a game's player base. Researchers can use this to uncover the player's demographic information, their gaming expertise or personality traits. These are some examples of the characteristics that can be uncovered.

- **Comparisons**: Surveys can also be used to compare the player's attitudes, perceptions and experiences. This information allows researchers to discern whether the player's expectations and experience differs for different regions, compare the games strengths and weaknesses with those from competitors, and make informed decisions before proceeding with the building of potential improvements.[82]

Inspired by Burks work[25], the intention is to have two surveys: a *Pre-Procedure Survey* and a *Post-Procedure Survey*. The pre-procedure survey will be used to inquire about aspects that might influence the player's experience and performance. Also it will be used to gather information regarding each player's gender, age, computer usage and current health. The post procedure survey will be used to garner information of the player experience in relation to the HUD. The hope is that it will be helpful in gauging how much it affected each user's enjoyment. Both the pre-procedure and post-procedure surveys will be issued to the test players. The manner in which the surveys would be issued is paper so that the results of player's experience can be recorded for later recollection.

4.7 Ethical Considerations

For this thesis and the development of the intended game prototype there were two ethical aspects that went under consideration.

The first aspect is regarding the game prototype and when the users will be asked to participate and play. Since the intention of the game is to induce motion sickness, the participants will be informed beforehand of the possible implications and discomfort they might experience, so that their participation is a well informed decision. However, there is a concern that alerting them beforehand might change their perception and might effect their experience and the results. Regarding this aspect, the test users involved could either be novice players or expert players. In the case of expert players the assumption is they would be aware that this experience might induce cybersickness. However, in order to avoid ethical issues it has been decided all participants before participating will be given a warning that by testing the game it might induce symptoms of cybersickness.

The second aspect is regarding the considerations to be taken when the test is taking place. Respondents would be given the contents and purpose of the survey so that they can make an informed decisions about whether they wish to participate or not. Any assurances, such as confidentiality or anonymity, will also be kept.[83] While participants are testing the prototype, a video recording of their experience for later review is considered. If that is to be the case the participants would be made aware before the recording. They would be given the choice if they want to be a part of the recording and also if they are willing to allow their recordings to be used for either the purpose of the presentation or for the research. Another thing to be considered is that when the project is complete what will be done to the video. Will it remain in the archives or will it be deleted. For privacy reasons if the decision is made to video record the participants, then after the study has concluded and their purpose has been fulfilled they will be deleted.

As of the time of writing, there is an another aspect that has arisen due to which additional considerations had to considered and existing ones reconsidered. This additional aspect is in the form of the Covid 19 disease[84]. This is a deadly infectious disease, which can potentially be transmitted from one infected person to others within the close proximity. To avoid the spreading of this disease, social distancing[85] was enforced in order to curb the spreading of the disease. Due to this recommendation the faculties of the universities had to close down and the virtual reality device and the computer system had to be moved from the studio to the apartment.

5
Planning

The master thesis is planned to be carried out over a period of five months (20 weeks).

5.1 Planned Method

The work for this master thesis has been divided into three phases: 1) preliminary study, 2) game creation and user tests, 3) formulation and visualization of results.

5.1.1 Preliminary Study

The preliminary study section of the thesis will focus on gathering information regarding the background and related work conducted within this domain. The preliminary study will consist of reading research papers and articles related to the subject. Online resources such as websites and blogs will also be utilized when felt necessary. Formally this section will comprise of the following:

- Looking at game theory
- Reading academic articles on Cybersickness
- Reading academic articles on First Person HUD
- Reading academic articles on methadologies.
- Studying flying games in general
- Studying and analyzing virtual reality games related to flying
- Studying and analyzing games with design choices related to different types of HUD
- Analysis of the game engines available and which one to use to create the game

The preliminary study section will be concluded with the creation of the project folder, formally, on the chosen game engine and with the participation of a small workshop on the available virtual reality headsets and how to use them in the studio.

The preliminary study will focus on answering these questions:

- What should the type of game prototype be and which engine should be chosen to develop it?

- Where to place the diegetic and non-diegetic HUD within the environment of the game?
- How to conduct tests and approach users in order to receive and document constructive feedback.

5.1.2 Game creation and user tests

This thesis will mainly use the results from the research to develop a prototype that will enable the observation and analysis of its various HUD approaches, on how to deliver information to the player in a plane's cockpit, in a flying simulation setting.

Hence the idea for a game that encompasses the aim of this study is a flying simulator. The basic idea, regarding the gameplay and mechanic, is the player would start off by flying in a aeroplane/jet from the perspective of within the cockpit while relevant HUD information are displayed in front of the player. While in flight, the player should be able to eject from the plane and enter free fall mode where they will be able to glide and or free fall to a certain destination or choose to enter back in the plane. While in free fall mode, the player will be falling towards the ground and will be surrounded by either trees, skyscrapers or clouds in order to induce the effect of cybersickness. However, the player will have nothing surrounding them apart from the HUD at the front and this state (absence of surrounding) be can utilized to explore and research the effects and frequency of cybersickness. The player will have the option to jump in or out of the plane while playing so they could observe the effects within the different environments as they please. An important aspect to mention here is that both the free fall and the in-cockpit mode will be situated within the same landscape/environment. The inspiration for this idea is similar to the mechanic presented in the game Arkham Knight[86] where Batman who the player is controlling is able to eject from his car and straight into flight mode[87]. But for this proposal instead of the car there would be a plane.

This concept will then be presented to the testers and it will be discerned if the different types of HUD have different effects on cybersickness.

5.1.3 Formulation and Visualization of Results

The intention is to have as many test users to test out the prototype. However, keeping the time frame in mind, there is a concern about the feasibility of gathering enough test users to conduct the tests and extract enough statistical observations to satisfy the production of quantitative results. In order to produce qualitative results thick description will be employed[88]. Based on the observations from this method and from the test user's own experience the tests will be assembled into one of the following categories: diegetic HUD, non diegetic HUD or a combination of both diegetic and non diegetic hud display items based on with which display category they experience reduced symptoms of cybersickness.

5.2 Time Plan

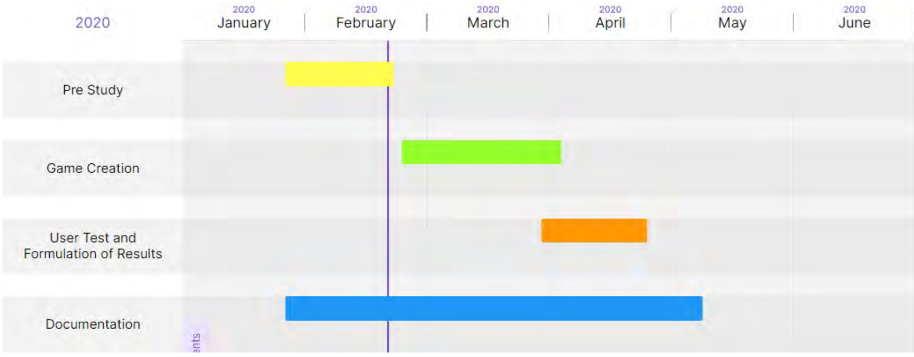

Figure 5.1: Gantt chart of time plan

- **Pre Study (Jan 27 - Feb 21)**: This section will consist of reading research articles to support the study of the thesis. This phase will be concluded by researching and then finalizing the game engine and the virtual reality equipment to better support the creation of the prototype.

- **Game Creation (Feb 24 - Apr 23)**: This section will comprise of the actual development of the prototype. The first part of this phase will consist of the cockpit design for the aircraft. Within this cockpit the location and design of the different types of HUD will be decided. Following the implementation of the flying of the aircraft along with the associated physical properties, will follow. Once that is completed the free fall mode for when the player will eject from the plane to observe the effects without the HUD will be implemented. Onward from that point, all these parts will be weaved together to create the intended experience.

- **Mar 30 - Apr 24**: This section consists of gathering the available test users in order to conduct the tests and then based on the observations and feedback received, to formulate the results.

- **Documentation (Jan 27 - May 8)**: Documentation will be an ongoing process that will take place throughout the thesis. In documentation notes about the process of development of the prototype will be provided.

6

Execution

For the execution of the project, the iterative process as mentioned by Tracy Fullerton within the book Game Design and Workshop was chosen[78]. Indicated in the following chapter are the steps ingrained in this process with a summary of my process of execution of that step.

6.1 Brainstorming

The primary step in this process of any creation is the ideation of the context of the project. For the purpose of the study the player experience to attain was sensation of being airborne in an aircraft. While being airborne the player would be able to view the different types of HUD while being situated within a cockpit or static setting.

Based on the intended experience a concept document was created. The purpose of this document is to list the 3 ideas of the prototype that were used to fit the context the study of this intended thesis. Below are those three ideas:

- **Virtual Skydiving**: The simplest approach for the first idea would be to confine it within the context of skydiving. The idea was that the player would start off by flying in an aircraft to a particular destination. Within the aircraft, the player would be seated in a static position within the cockpit. The cockpit would have the required HUDs surrounding the player so that they could experience the motion with both types of HUD. Once the destination was reached the player would be ejected from the aircraft. Within this setting the player would not have the HUDs surrounding them and would not be static anymore and could chose to move freely without the confines of the cockpit. Using these two states the required could lead to the extraction of data from the users on both methods in the same testing session, giving a chance for them as well to experience them both in a tight time frame and be able to compare their probable Cybersickness more accurately.

- **Aerial Assassination**: The second idea was to create a scenario where the player would assume the role of an assassin living on a remote island. He would receive contracts via calls and after accepting them would embark towards his victim on his aircraft. Once he had reached near his contract in order to escape and avoid unnecessary detection would eject from the plane from way up and try to gain entry somehow while free falling and parachuting down.

- **Smoke jumpers**: The third idea and the one that was eventually chosen for this study is based on the above idea. However, the setting is different. The prototype will be based on paratrooping firefighters known as smokejumpers. Smokejumpers are an elite class of firefighters who combat forest fires by flying to the far off burning region of a forests in planes, drop towards the burning fire and try to combat the flames from within.

  To fit the context of the game, the idea is consisted of two parts. The initial phase was to be the player's character, the firefighter getting in the plane and flying towards the burning region. Within this phase, the player would be situated within the cockpit and surrounded by both the diegetic and non-diegetic huds. Both of these HUD would be switchable with the press of a button so the user can experience the resulting effects for each of them. The players will be required to fly the plane and maneuver around obstacles to induce heightened feeling of cybersickness so it can be used to observe the difference with the different types of HUD.
  The second phase of the game would be initiated when the player in the plane is able to successfully avoid all the obstacles in his path. The second phase would consist of the player being re-situated in the forest alone without the plane with the fires surrounding him. Within this phase the player would be equipped with thrusters which can be both be used for flying towards the burning location and can also be used to fire a stream of water to put out the fire. By having the player free flying towards the required locations the hope is that the player can experience any sort of cybersickness and observe if the resulting effect is greater or less compared to the cybersickness experienced with the huds in the previous phase.

6.2 Planning Change

Before proceeding towards the execution of the prototype discussed in the previous section, changes were made towards the idea. These changes resulted because of the modification to the research question. The previous iteration to the research question involved observing the effects of the cybersickness with the the diegetic and non-diegetic HUD with the presence of a static element such as a cockpit. However, after internal discussion it was felt that in that case there were much too elements at play and it was more important to keep focus on just the diegetic and non-diegetic HUD. More details regarding these changes have been discussed in 8.2. Due to this change the final prototype did not consist of the "free fall" mode and more represented a flight simulator.

6.3 Sketches

Once the basis and foundation of the intended experience was decided the next phase in the process was to generate some concept sketches for the design of the diegetic and non diegetic displays, cockpit and the intended experience and game. With the help of sketches, it is easier to realize your vision and more practically approach the idea and test out its core design without spending too much time this early in the development stage, thus helping to solidify the decision making of the game design. Besides this method helps in keeping the gameplay in focus rather than programming and the problems that can arrive from there, as they are now irrelevant. Another benefit is that you can respond in real time to player feedback. If players come up with an issue or idea, you can incorporate it immediately and see how it works.

To begin the process rough sketches, of the cockpit that would surround the player, were made as illustrated in Figure 6.1. The notion behind the design of the cockpit was to have as big an area as possible, and from the windows through which the user can perceive the environment surrounding the plane. The rationale behind this decision, was to open the surrounding terrain to the player so that the potential premonition of motion sickness can surge.

Along with sketches of the cockpit another important component for this study was the concept and outline of the HUD. Both of the respective display items would be identical. Only the domain in which they would be situated in and placed, would be changed. Keeping the theme of the prototype under consideration it made sense to have display items that would depicted similarly in an actual cockpit of an airplane i.e. Flight instruments[89]. Several sketches were made for representing different types of flight instruments. For the purposes of this thesis the following flight instruments were selected and finalized to be displayed as HUDs:

- **Tachometer**: A tachometer is an instrument that is used to calculate and show the number of revolutions per minute (RPM). An airplane requires one tachometer for each of its installed engines. For this project it was decided that the plane would have one engine hence one tachometer would suffice. [90]

- **Altimeter**: An Altimeter is another basic flight instrument that informs the pilot how high the plane is flying from the ground. [91]

- **Fuel Indicator**: A fuel indicator informs the pilot how much fuel the plane has consumed in flight so far and how much fuel remains. [92]

- **Airspeed Indicator**: An airspeed indicator is another fundamental flight instrument that is used to measure the forward airspeed of the aircraft. It is measured in knots. [93]

- **Attitude Indicator**: An Attitude Indicator (AI), Attitude Director Indica-

Figure 6.1: Sketches drawn for the design of the cockpit and the design elements

tor (ADI) or Artificial Horizon (AH) provides flight crew with essential information about aircraft attitude relative to the real horizon, when the latter cannot be determined because of either poor forward visibility or dark night conditions.[94]

- **Throttle**: The throttle is used to control the thrust output generated by the engine. This component in this game will be used to depict the throttle lever in a plane.[95]

- **Flaps**: Flaps are a kind of device mechanism that is used to gradually reduce the stalling speed of an aircraft wing at a given weight. Flaps are usually mounted at the edge of the wings. Flaps are used to reduce the take-off distance and the landing distance. Flaps also cause an increase in drag so they are retracted when not needed. For this project they would be used to indicate the degree to which the flaps have been deployed so the players are aware of the amount of potential drag being produced, which will help them in landing the plane. [96]

6.3.1 VR Sketches

VR sketches, a relativly new concept is the concept drawings within the VR space. Numerous VR experiences require 3D model design and animation for e.g. Mass effect[97], and a critical part of the process involves prototyping and testing full 360˚ scenes. This is where issues arise as the monitors, design tools (for e.g. Photoshop, GIMP etc.) and paper sketches are all flat. Traditional 2d tools can not be used to observe the models in 360 degrees. To bridge this gap there are numerous widely used VR sketching applications available like Google Tilt, Gravity Sketch amongst numerous others. For my designs I availed the use of the application PaintLab[98].[99]

6.4 Prototype for the Plane and Cockpit

Advancing from the conceptual prototypes discussed in the previous section, advancement were made towards more concrete prototypes that would ultimately be used in the final prototype. The first step in this process was the design of the cockpit. Different designs were tested out using various meshes and a combination of those either used from Unity or created through Blender as demonstrated in Figure 6.2 and 6.3.

Similar method was used to create different digital prototypes for the planes.

However, after trying out different versions of each prototype of the cockpit using my limited expertise of 3d designing none appeared viable to fit within the context of the game idea and experience. For this purpose, it was ultimately decided to

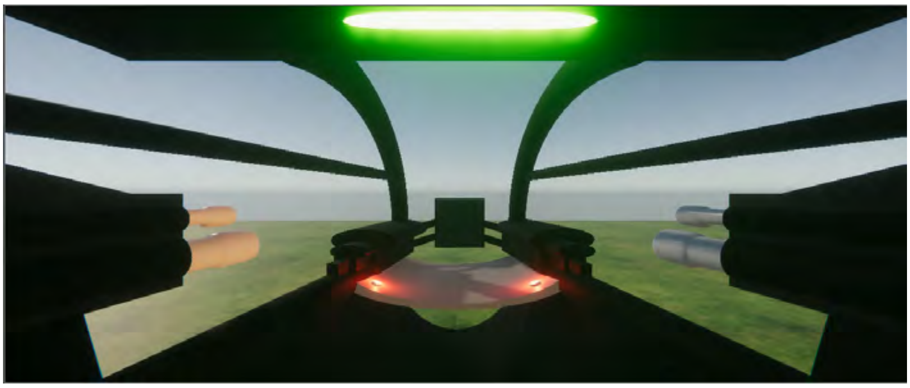

Figure 6.2: Initial cockpit design

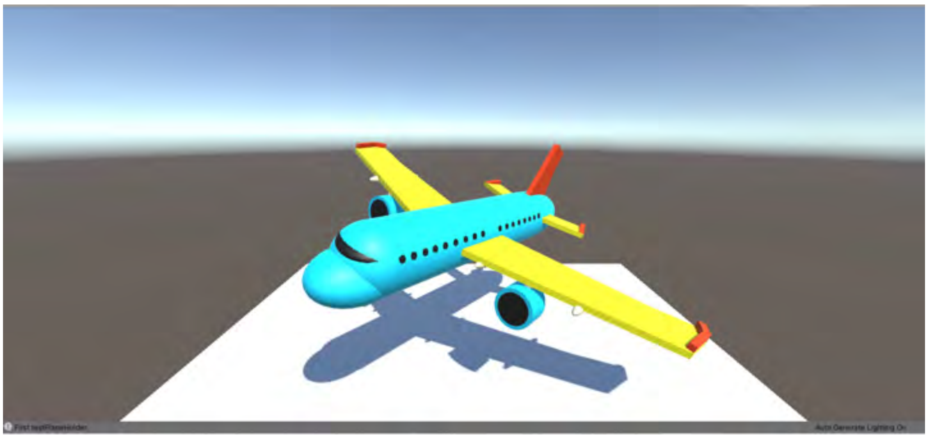

Figure 6.3: First Model of the airplane design

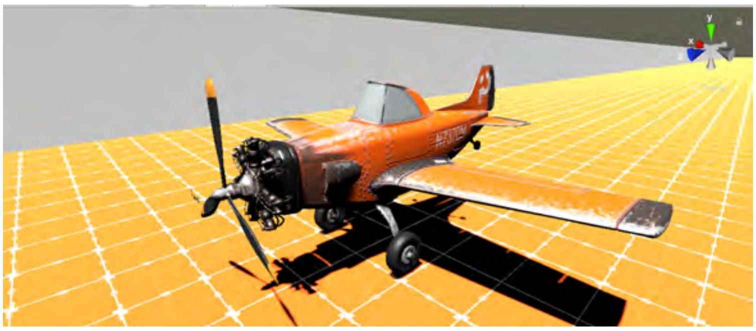

Figure 6.4: Model of the airplane used in the project

use a free 3d model of a Cessna aircraft as illustrated in Figure 6.4. Within this model the outline of the plane and the interior cockpit were available fulfilling both requirements for the study. Slight modifications were made to the interior cockpit of the plane for the purposes of the study. These modifications will be discussed further in detail in the later sections.

6.5 Configuring the plane

The next step in the process once the design of the plane and the cockpit had been finalized was to configure the plane to fly around the environment. The code structure integrated for this project has been illustrated in Figure 6.5 with a description of each component and their connection following it.

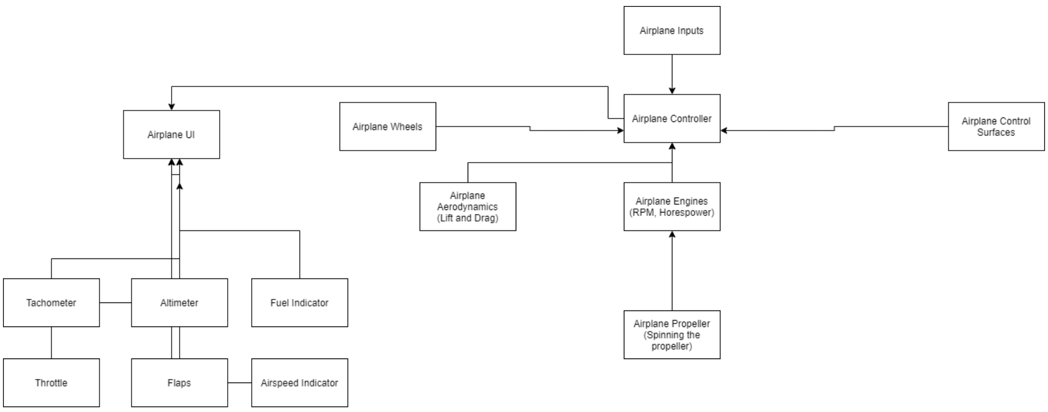

Figure 6.5: Code Design Structure

6.5.1 Airplane Inputs

This script has been created to receive and handle all the input received by the user from the keyboard and/or a Xbox Controller. All the information received by this script will be fed to Airplane Controller script. The code structure of this component is illustrated in Figure 6.6.

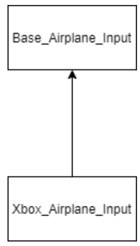

Figure 6.6: Airplane Input component's code design structure

The base airplane input script by default will contain the keyboard inputs. It contains a virtual method *HandleInput* that is responsible for receiving and controlling all the information from the keyboard. The Xbox Airplane Input script is responsible for handling the input from the Xbox Controller. It achieves this by overriding the virtual method HandleInput.

6.5.2 Airplane Controller

The Controller script is responsible for each of the different components of the plane. Its main responsibilities include receiving information from the Airplane Input script and then providing the relevant information to the different components of the plane. The code structure of this component is illustrated in Figure 6.7.

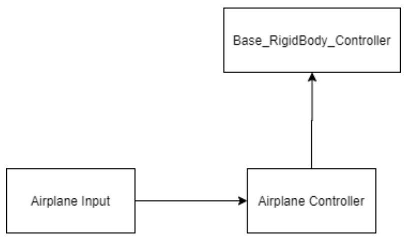

Figure 6.7: Airplane Controller component's code design structure

The Controller script has the Rigid body[100] attached to it. The Base rigid body controller is composed of all the basic functionalities that are required to be done over and over again. The airplane controller component inherits from the rigid body controller. The Airplane Input component provides the controller script with all the required information.

6.5.3 Airplane Aerodynamics

This script is responsible for creating the lift and drag for the airplane. This script is dependent on the Airplane Controller script for information to create the required forces.

6.5.3.1 Lift

The basic theory behind the lift force of an airplane is that as the plane gains more and more speed the air goes faster and faster over and under the wings of the plane as it moves forward. The air present at the top of the wing is at lower pressure and the air present under the wing is at a higher pressure. This variance between the pressure causes a lift in the airplane as the higher pressure under the wing strives to go up. To simulate this in code first the planes position in the Y axis in world space coordinates[101] is retrieved and store it in a variable *liftDir*. Then the lift power is calculated by the following formulae:

$$liftPower = \text{forwardSpeed} * \text{maxLiftPower}$$

where the forward speed is the velocity of the plane in its z axis and the max lift power is a constant value defined in the beginning. To calculate the lift force the following formulae is being used and applied on the plane:

$$liftForce = \text{liftDir} * \text{liftPower}$$

6.5.3.2 Drag

As the plane advances forward, the air creates a resistance as the air has a density to it. So as the airplane thrusts forward the air particles creates a resistance which is normally known as drag. As the plane garners more and more speed the drag also increases creating a force in the backward direction until a threshold is reached where the plane can not go any more faster because of the drag force hindering it.

$$speedDrag = \text{forwardSpeed} * \text{dragFactor};$$

where dragFactor is a constant scalar value which was set to 0.01 in the beginning. Once the speed of the drag had been calculated the final drag force was calculated by using the following formulae and applied to the plane:

$$finalDrag = \text{startDrag} * \text{speedDrag};$$

where startDrag is the initial drag set on the plane at the beginning. This value is retrieved from the rigidbody[100] of the plane.

6.5.3.3 Airplane Characteristics

The airplane characteristics refer to the rotation of the plane i.e. the orientation and attitude of the flying plane in all three dimensions. The following characteristics of the plane have been integrated as part of the project:

- **Pitch**: The pitch axis is parallel to the plane of the wings with its origin at the center of gravity and directed towards the right wing tip. A pitch motion is an up or down movement of the nose of the aircraft.

  In terms of code to calculate this pitch force, first the angle between the Z axis of the plane and the Z axis of the ground in world space orientation is measured. Once we have the angle in order to get the pitch torque the input for the pitch is multiplied with a pitch speed (a constant variable that controls the speed with which the plane will pitch) and the axis around which it is going to rotate which in this case is the plane's X axis.

- **Roll**: The roll axis is perpendicular to the the pitch and yaw axes with its origin at the center of gravity, and is directed towards the nose of the aircraft. A rolling motion is an up and down movement of the wing tips of the aircraft.

  In terms of code, the roll force calculation is pretty similar to the pitch force calculation. The foremost part to calculate is the angle between the Z axis of the plane and the Z axis of the ground in world space orientation. With this angle determined in order to get the roll torque the input for the roll is multiplied with a roll speed (a constant variable that controls the speed with which the plane will roll) and the axis around which it is going to rotate which in this case is the plane's Z axis.

- **Yaw**: The yaw axis is defined to be perpendicular to the plane of the wings with its origin at the center of gravity and directed towards the bottom of the aircraft. A yaw motion is a movement of the nose of the aircraft from side to side.

  In order to calculate the yaw it is not necessary to determine the angles initially as the roll and pitch angles play a more fundamental role in the motion of the plane. To calculate the yaw torque, the input for the yaw is multiplied with a yaw speed (a constant variable that controls the speed with which the plane will yaw) and the axis around which it is going to rotate which in this case is the plane's Y axis.[102]

- **Banking**: Banking a plane means to manipulate the flying control surfaces in such a way, that if one was to take an imaginary straight line (roll/longitudinal axis) from the front to the back of the aircraft, said aircraft will now rotate/roll to the left or to the right along that axis[103].

  In order to calculate this value first the value of the roll angle which is being calculated in the handle roll function is transformed into values between -1 and 1 to distinguish between the different directions of the plane roll. Once roll angle has been restricted and converted, we can obtain the bank torque by multiplying this value with the roll speed (a constant variable that controls the speed with which the plane will roll) and the axis around which it is going to rotate which in this case is the plane's Y axis.

6.5.4 Airplane Engine

The engine script is responsible for calculating measurements such as RPM, Horsepower etc. This script is dependant on the Controller script for the required information. The reason for having a separate engine component is to have a more modular approach since planes are usually equipped with different and multiple engines. Following are the entities that are being calculated by the engine component of the plane:

6.5.4.1 Forward Force

The first entity that is being calculated by the engine is the forward force/power being produced by the engine when the throttle from the Airplane Input component is being manipulated. In order to calculate this value the initial step is to clamp the throttle value being produced by the Airplane input component between 0 and 1. Then this throttle value is multiplied with a maximum force defined. This maximum force is stored in a variable and it indicates the maximum force that can be generated with the equipped engine. By multiplying these values we get the final power generated by the engine. When this value has been obtained we can apply this value to the forward axis/Z axis of the plane.

6.5.4.2 RPM

The second entity that is being calculated by the engine component is the RPM (Revolutions per Minute). In order to compute this value first a maximum RPM variable is created and defined. The value of this variable is set to 2550. This value is in accordance to the actual maximum rpm generated by the model of the airplane that is being used i.e. Cessna 152[104]. To get the RPM we take this value and multiply it with the clamped input throttle value being produced by the Input component.

6.5.5 Airplane Propellers

The propeller script is responsible for calculating the speed of revolution of the propellers on the plane. It extracts the rpm information from the engine component and manage the rotation of the propellers. To calculate the required Degrees per second for the propellers the following formulae has been used:

$$\textit{Degrees per second} = (\text{RPM * 360})/60$$

where RPM is the current RPM provided by the engine component.

6.5.6 Airplane Control Surfaces

Airplanes have different control surfaces. This script is responsible for handling the animations of each these different control surfaces during flight. For the purposes of the project following are the control surfaces that are being animated:

6.5.6.1 Rudders

The rudder is a primary flight control surface which controls rotation about the vertical axis of an aircraft. The rudder is a movable surface that is mounted on the trailing edge of the vertical stabilizer or fin.[105]

6.5.6.2 Ailerons

Ailerons another primary flight control surface control movement about the longitudinal axis of an aircraft. This movement is referred to as "roll". The ailerons are attached to the outboard trailing edge of each wing and, when a movement input is made, move in opposite directions from one another.[106]

6.5.6.3 Elevator

An elevator is a primary flight control surface that controls movement about the lateral axis of an aircraft. This movement is referred to as "pitch". Most aircraft have two elevators, one of which is mounted on the trailing edge of each half of the horizontal stabilizer. When a manual input movement is made, the elevators move up or down as appropriate.[107]

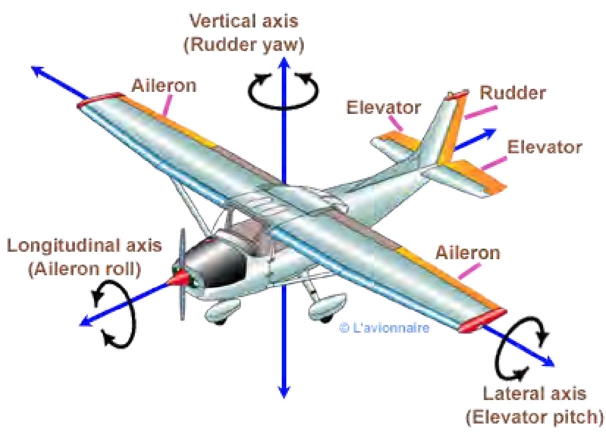

Figure 6.8: Cessna flight control surfaces.[15]

6.5.7 Airplane Wheels

The wheel script is responsible for handling the mechanism of the airplane wheels. The mechanisms of the plane include applying brakes on the front wheel and using

Figure 6.9: Altimeter HUD for the panel

the back wheels to steer the plane.

6.5.8 Airplane UI

This component is responsible of retrieving the information from the Controller script and then further controlling the flight instruments to calculate each of their respective measurements and displaying them on the HUDs. The design for each of the flight instruments of the Airplane UI component and the motivation behind their sketch is described below. The description regarding the operation behind each of the flight instruments have been provided in the previous sections of the report.

- **Altimeter** is used to measure and display the height gained by a plane from the ground during flight. The design of the altimeter for this project has been illustrated in Figure 6.9.

  In this design the longer dial pointer on the altimeter is known as the hundred pointer and it indicates the height from the ground in the hundredth value represented in feet. Similarly the shorter pointer is known as the thousand pointer and indicates the height of the plane in thousandth value represented in feet.

  The brown panel behind the altimeter and all of the following flight instruments have been added to give a more prominent look so in the game scene the user will be easily be able to distinguish between the HUDs.

- **Tachometer** is another basic flight instrument which is used to calculate and display the revolutions per minute RPM. The design of the tachometer for this project has been illustrated in Figure 6.10.

- **Airspeed Indicator** is a flight instrument which is used to measure and indicate the airspeed of the flying airplane. The design of the airspeed indicator has been illustrated on Figure 6.11.

- **Fuel Indicator** is used to measure the fuel consumed yet so far within the

Figure 6.10: Tachometer HUD for the panel

Figure 6.11: Airspeed HUD for the panel

flight of the plane and portray to the user the remaining fuel. The design of the fuel indicator for this project has been illustrated in Figure 6.12.

- **Attitude Indicator** This particular flight instruments makes aware to the user the current orientation of the airplane with respect to the ground. The design of the attitude indicator has been illustrated on Figure 6.13.

- **Throttle** This flight instrument is used to indicate the amount of the throttle being applied by the user to the engine, The design for the throttle lever for this project has been illustrated in Figure 6.14.

- **Flaps** are controllable surfaces that can be deployed to reduce the stalling speed of an airplane. The flaps HUD is used to convey to the user if first, the flaps have been deployed and second, to which degrees they have been positioned. The design for the flap lever for this project has been illustrated

Figure 6.12: Fuel indicator HUD for the panel

Figure 6.13: Attitude Indicator HUD for the panel

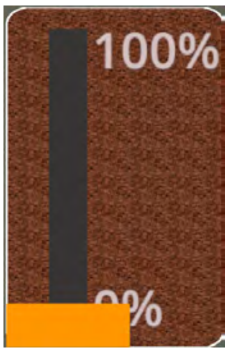

Figure 6.14: Throttle HUD for the panel

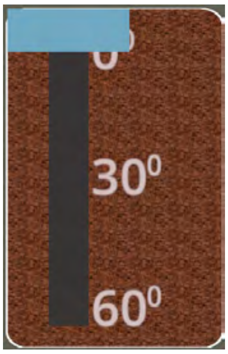

Figure 6.15: Flaps HUD for the panel

in Figure 6.15.

6.6 Switching between the different types of HUD

As explained previously in section 1.4, the intention in the beginning of the study was to create an environment for the player where they would be able to comfortably transition from one type of HUD to another and back again (diegetic and non-diegetic hud). The next step in the execution process was to plan and decide the orientation and position the respective display elements would be situated in within each of the respective HUD type space.

With the culmination of section 6.5, a working airplane complete with the different HUD design and implementation. Using this plane configuration, the player could now be placed within the cockpit of the working plane and could now survey the virtual environment using the HTC Vive headset. Now the next step in the execution process was to populate the players view with the working and different types of HUD.

6.6.1 Non-diegetic HUD

In terms of game UI or HUD, Non-Diegetic is what you would normally associate a typical game display element, an overlay on top of the game. They have the freedom to be completely removed from the games fiction. Non-Diegetic HUD usually represent health and ammo bars in games of the player character. Non-Diegetic UIs are normally represented in the two dimensional space.

In regards to the intended game being created, this overlapping overlay would consist of placing the different HUD elements created around the players view. Within the non-diegetic realm, these HUD elements would constantly follow the gaze of the player as he viewed the environment. In terms of programming this meant that the HUD elements would always follow the position and orientation of the player's gaze.

Figure 6.16: The arrangement of the HUD elements in the non-diegetic realm of the game.

The placement and position of the HUD elements around the player's gaze is under accordance to the work of Caroux and Isbister as mentioned in section 3.1 and as illustrated in Figure 3.2. According to their work for games that have a first person/perspective view, the permanent HUD elements should be placed at the bottom middle, bottom left and bottom right positions. The same arrangement is used for the non-diegetic HUD for this study as illustrated in 6.16. An added benefit with this arrangement was that it provided that least bit of obstruction to the player's view.

6.6.2 Diegetic HUD

On the hand there is the Diegetic HUD, which exists in a game world instead of being overlaid onto the game, becoming a part of that games fiction. For example a player could press a button to make their character look at their watch to check the time.

Within the context of this game, the most obvious fictional element to place the diegetic HUD elements was the cockpit of the plane. Instead of the HUD display elements following the player's gaze, the same HUD elements within the diegetic realm would be placed permanently over the cockpit as illustrated in figure 6.17. From their position in the cockpit the player could survey the diegetc HUD by looking at the cockpit whenever he felt necessary. With the diegetic HUD the players could chose to look at them as closely and from whichever angle they preferred.

It was programmed as such that the player could switch between these two different types of HUD with the press of a button on the keyboard. This transition could be made at any time during the flight or even when on the ground to assist the player in making the relevant observation with whichever type of HUD (diegetic or non-diegetic) they preferred.

Figure 6.17: The placement of the HUD elements in the diegetic realm of the game.

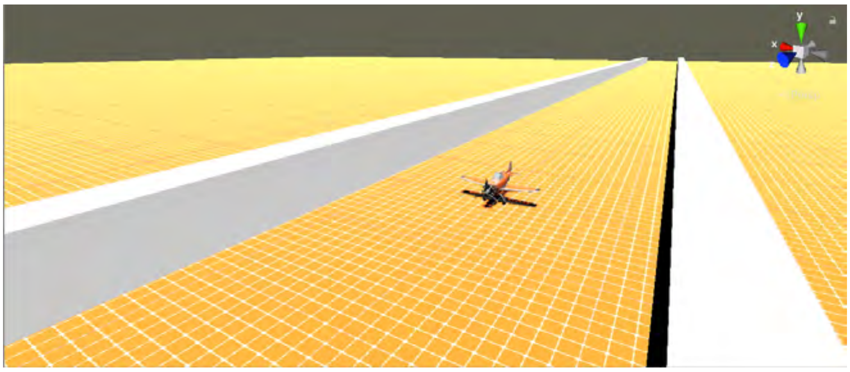

Figure 6.18: Initial test environment for the project

6.7 Environment Prototypes

Once the plane had been successfully configured and flying correctly the next phase in the project was to design for the environment within which the plane would be soaring around.

For the initial phase of configuring the plane a test environment was created. The test environment composed of a simple plane and long cubes along each left and right side of the plane. The purpose of these cubes were to provide a reference to the user when takeoff was being initiated in VR.

Once the plane had been successfully configured, a more robust environment was designed and created. The reason for creating a slightly more rich environment was to test the soaring and flying of the airplane. This environment provided a surrounding where the initial flights of the plane in VR and observed if the feeling of motion sickness was being induced.

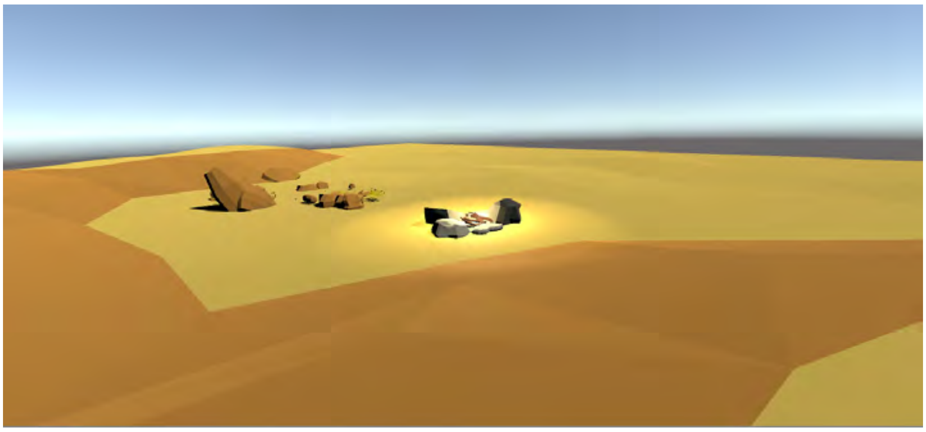

Figure 6.19: Intermediate test environment for the project

With the intended movement of the plane tested and the notion of cybersickness being achieved, the final step in the environment design was to create the final surrounding in which the project's experience would take place. Several concepts and ideas were drafted to observe what kind of habitat would encompass the user and the plane. Amongst all the ideas and schemes two were finalized and concepts of these environments were designed.
With the intended movement of the plane tested and the notion of cybersickness being achieved, the final step in the environment design was to create the final surrounding in which the project's experience would take place. Several concepts and ideas were drafted to observe what kind of habitat would encompass the user and the plane. Amongst all the ideas and schemes two were finalized and concepts of these environments were designed.

The first idea involved a forest setting from where the plane would take off and roam around. The base for this environment thus was created Unity Terrains[108]. The base of this environment composed of the ground and the surrounding mountains that would be enclosing the surroundings. Once the base had been defined different textures were used to paint the environment to distinguish between the ground, lake and mountains. Once the tone for the environment had been painted the final step in the design was to populate the environment with forest elements that would bring the forest environment alive.

To obtain such forest elements free environment assets were obtained from Unity's asset store[109]. The collection of free assets obtained composed a collection of different trees, bushes, grass, plants etc. Some of these free assets have been illustrated in Figure 6.20. A combination of these assets were placed around different parts of the terrain to finalize the design and concept of this environment.

The second concept drafted for the game was a small valley in which a small functioning airport would be situated. The small airport would be composed of a main airport building, a couple of airplane hangers, a control tower and the runway. All

Figure 6.20: Collection of free environment assets from Unity's Asset Store

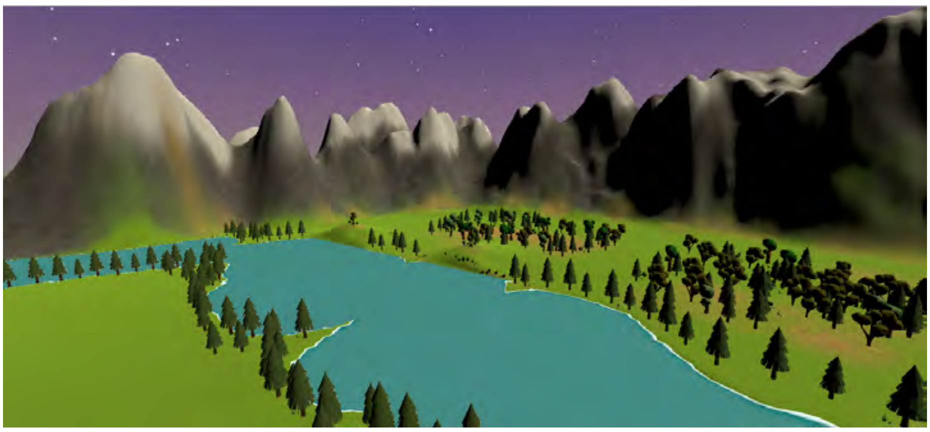

Figure 6.21: Forest environment design

Figure 6.22: The airport designed for the valley environment

Figure 6.23: Valley environment design

of these building items were designed and built using a combination of Unity 3d objects. The 3d objects were used to create the base of the buildings and then different materials were placed on top of them to give them their final and distinguishing looks.

Similar to the forest scene, the base of this environment was created with the help of Unity Terrains[108] and the tone was set using different material on the base to set apart the ground and the surrounding mountains. The same collection of free environment assets from the forest environment were used to populate the rest of the surroundings. The final look of the environment is illustrated in Figure 6.23.

6.8 Obstructions

Once the prototypes for the environments and the plane had been created the final phase in this process was to combine these two entities together. Once combined this amalgamation could be used to create an experience for the user where they would be able to take flight in the plane, survey the environment from within the

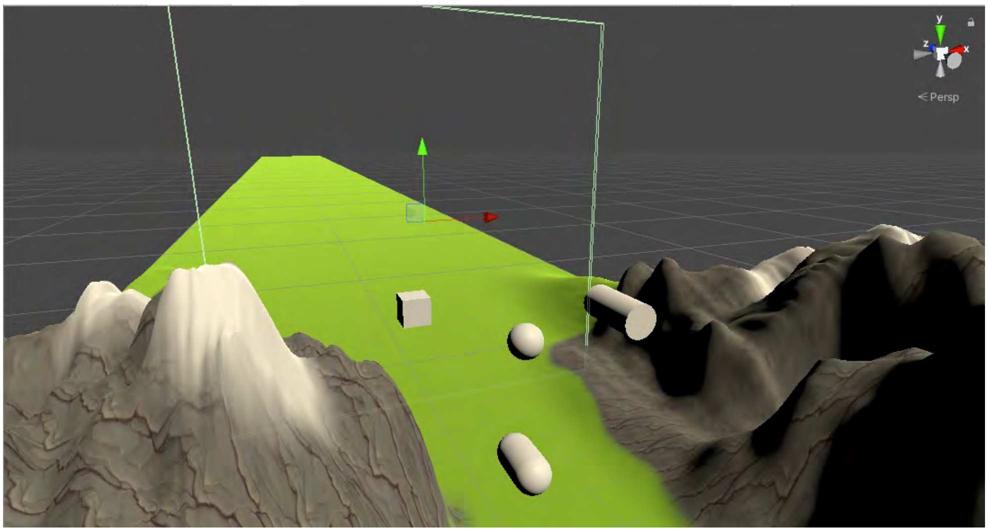

Figure 6.24: The shapes used as obstructions and the highlighted plane from which they are instantiated

cockpit and the selected HUDs. However, after some initial testing it was felt that just operating the plane to fly around the environment in the cockpit would not suffice enough to invoke the effect of cybersickness within the users to ultimately make conclusions. The reason for this was some users might be content in just gliding around the map in a linear or in a constant direction. It was experienced flying in such a manner had less probability of supplicating the effects of cybersickness.

Based on this observation, a couple of ideas were drafted to create a more engrossing and engaging experience by forcing the user to somehow maneuver around the environment when engaging in the tests. The first idea encapsulating this was to set a task for the user. The task being after takeoff, the player would be required to fly towards a predetermined destination. However, after takeoff once the player has gotten used to the controls and how to fly the plane right on the way to the destination obstructions would be instantiated and would be proceeding towards the players. The task of the player would be to avoid these obstructions as he progresses towards the destination. The obstructions consisted of Unity's basic 3d shapes i.e. cubes, spheres, cylinders and capsules.

The obstructions were instantiated from a random location on a vertical plane and after a random time from the plane as highlighted in Figure 6.24. Also it was ensured that the speed with which these obstructions were moving towards the player was random as well. The reason for maintaining all these randomness variables was to ensure the player was not able to identify the patterns and resume flight in a more straightforward manner.

The other idea and the one that was ultimately used in the player tests comprised of walls as obstructions. Vertical walls were placed at different positions along the path of the player to his destination. On the flight towards the required end point the player would have to maneuver the plane around these vertical static walls in

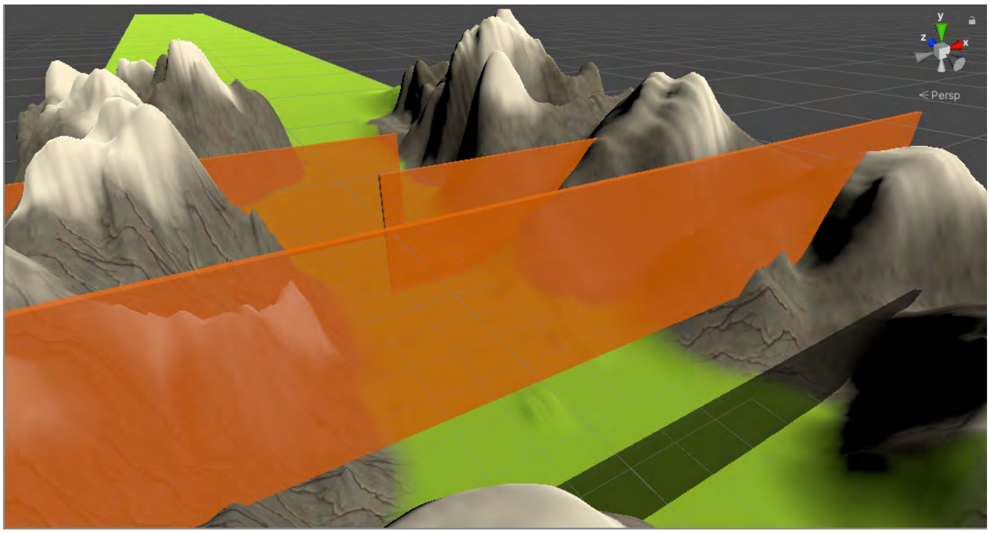

Figure 6.25: The static walls used as obstructions

order to avoid them and advance towards the end point.

The rationale for adopting this idea instead of the previous one was because it was felt that with the previous idea there was an excess amount of cybersickness experienced which was not necessarily safe and advisable for the users. Another advantage with this design was that it provided the user with a more appropriate setting for getting used to the controls. Since the upcoming wall obstructions were placed in a predetermined location and the user could identify their upcoming location and gradually maneuver them. Also the walls were strategically placed around the map in such a way that it helped the user get used to the different movements of the plane. For example as illustrated in Figure 6.25, the first wall was placed at the basic height of the plane during flight. In order to avoid this wall, the player would have to pitch the player up. Similarly the next wall was placed at a slightly higher vertical position then the previous wall so in this design the player would have to pitch down the plane in order to steer clear from the wall. The forthcoming walls after this were placed at a slightly left and right position. The reason for situating them in such a way was to educate the players and get them equipped with the banking motion of the plane.

6.9 Evaluation Process

The evaluation/test phase of the project was composed of three phases. The area where the tests were conducted was within the apartment. The virtual reality device that was used for the tests was the HTC Vive[48]. Due to the nature of the setup and configuration of the Vive computer had to be placed in the middle of the apartment so the sensors of the Vive headset could be placed on either side. The test of the virtual environment comprised of the user surveying the environment using the HTC Vive headset and controlling the movement of the plane using keyboard controls.

Each user test session consisted of three parts. Before the test was commenced, the process was initiated by explaining the purpose of the study, how many phases would take place followed by an explanation of what to expect in each phase. A total of five test users were gathered to conduct the tests. The test session commenced by the users filling out the pre procedure survey. Once completed they proceeded to test the virtual environment and played the prototype. Once satisfied, the test session was concluded by conducting the post procedure survey. Each test session approximately took 20 to 30 minutes, the variation of which is dependant on the time the players spent in the virtual environment. More details regarding each of the phases are provided in the following sections:

6.9.1 Pre Procedure Survey

The pre-procedure survey shown in Appendix A asked questions that gauged general information about the test players. These included questions about gender, age, computer usage, and their current health etc. Within this survey the users were also asked if they were aware of the difference between the different types of HUD. If not, the difference was explained.

6.9.2 Virtual Environment

Once the users had completed the pre procedure survey, they were asked to participate in the created virtual environment created. Before they engaged in the experience, they were informed of the purpose of the study, what they should be expecting in the game and the associated possible induction of cybersickness within this experience. Once it was ensured they understood the requirements and were aware of the potential risks involved the next description was given on the controls with the game.

Next the controls were elucidated, they were fitted with the HTC Vive headeset and were given a few moments to get used to the default virtual environment and get a feel of their surroundings. When comfortable and the users were accustomed to this new environment the simulation was started. Once started, first the test users were given a few moments to observe the surroundings of the cockpit environment. When accustomed to they were asked to initiate the takeoff as explained with the controls previously. Once in the air the users were given all the time they were comfortable with to glide around in the plane within the virtual environment created. While flying they were instructed to switch between the diegetic and non diegetic HUDs with the appropriate control to observe their experience with them and their effects. Most of the users who participated in the study were skilled computer and game users and required no help for maneuvering the plane. For the novice users assistance was provided in the form of assistance in the controls. The controls were operated by another person while they just controlled the switching between the different HUDs.

After that the users had become familiar with the environment and the maneuvering of the plan they were asked to make way towards the required position while avoiding the obstacles. For the novice users they completed this task themselves and for the inexperienced individuals this was done for them.

6.9.3 Simulator Sickness Questionnaire

Following their navigation and gliding through the virtual environment, the participants of the test were then asked to fill out a Simulator Sickness Questionnaire (SSQ) shown in Appendix B. The SSQ is a standard method of measuring symptoms of both simulator sickness and cybersickness. The SSQ used in this study was an edit of one by Kennedy, Lan, Berbaum, and Lilienthal [7] edited by the UQO Cyberpsychology Lab [8].

In the SSQ, participants ranked the degree of any symptoms present on a scale of none, slight, moderate, or severe. The Simulator Sickness Questionnaire is displayed in Appendix B.

6.9.4 Post Procedure Survey

Displayed in Appendix C, this survey was structured in a way to ask questions and extract information regarding the different HUDs in order to gauge how much it affected the user's enjoyment of the scene and on the ratio of cybersickness observed with each of the different HUDs. The questions asked included those about how helpful/distracting the HUD was, their opinions on how noticeable it was, whether or not they noticed any changes, if one was better then the other and any further comments they had.

6.10 Playtest

A total of five participants agreed to participate in the playtest session. The occupation of the participants ranged from working individuals to students. In this thesis, for the purposes of anonymity the participants will be tagged as User followed by alphabets: A, B, C, D, E. As discussed in the previous section 6.9, the playtest consisted of 4 phases: a Pre Procedure Survey, engaging in the Virtual Environment, filling out the Simulator Sickness Questionnaire and finally concluding the test by filling out the post procedure survey. The pre procedure survey as illustrated in Appendix A was structured to gauge out the test user's occupation, their computer usage and their current knowledge of the virtual world and the different types of HUD.

Once finished with the pre procedure survey, the next phase in the test session was the user gliding around the virtual environment. The aim within this phase was that the player would use this opportunity to switch between the different types of HUD as mentioned in the section 6.5 and illustrated in figures 6.16 and 6.17. The players were encouraged to switch regularly between the diegetic and non-diegetic HUD regularly and whenever they felt necessary so they could make the relevant observations with each type.

Following their experience in the virtual environment, the test users were asked to fill out a Simulator Sickness Questionnaire as shown in Appendix B for each type of HUD so that it could be determined which symptoms and to what degree they were effected.

Following the Simulator Sickness Questionnaire the test session was concluded by asking and filling out the post procedure survey. The pre procedure survey was the same for all participants and contained the following inquiries:

- On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?
- On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?
- Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.
- Do you have any further comments concerning the HUD?

A summary of the answers to this survey by the test users are presented in the following sections.

6.11 User ’A’

Based on the results of the pre procedure survey, User A is 24 year old male student currently engaged in his last years of masters in Information Technology. Due to the nature of his studies his computer usage comprises of half a day almost 5 days a week of assignments and reporting. However, playing games was a very rare activity for him consisting of only a few times a month maybe. In regards to exposure to virtual reality he had a brief experience once before trying out the PlayStation VR. This was the extent of his virtual reality usage. At the time of the test the individual claimed to be in perfect health. The user also stated that he seldom experienced motion sickness. This User was unaware of the different types of HUD being explored so it was clarified and explained to him with examples.

The SSQ results of User A are illustrated in Figure 6.26.

Despite being a novice gamer, User A got accustomed to the controls quite easily and required no assistance in gliding around the environment and eventually the end point.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?** Based on his experience user Asad set the scale to 5. The rationale behind this decision was that on one hand the non diegetic

Symptoms	Severity
General Discomfort	Slight
Fatigue	None
Headache	None
Eye Strain	Slight
Difficulty focusing	Slight
Salivation increasing	None
Sweating	None
Nausea	Moderate
Diffuculty concentrating	Slight
Fullness of the head	None
Blurred Vision	Slight
Dizziness with the eyes open	Slight
Dizziness with the eyes closed	None
Vertigo	None
Stomach Awarness	None
Burping	None

Figure 6.26: Simulator Sickness Questionnaire results for User A for both types of HUD

display was a bit annoying as it always followed your view so it was difficult to focus on the rest of the environment. However, since this information was readily available within the view sight of the user extra effort did not need to be placed to look for it as it was in the case of the diegetic display items.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?** User Asad rated his experience with the diegetic displays as 7 from 10. According to Asad, diegetic displays provided a more pleasant experience as it was not distracting. However, when looking for the required information on the cockpit at the diegetic display it takes the focus away from the front of the cockpit for a while which in case of maneuvering a plane or a car can not be great.

- **Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.** As per User Asad's observation there was no discernible difference in the amount of cybersickness experienced between the diegetic and non-diegetic HUD displays. He experienced the same symptoms and equal amounts of cybersickness when gliding around in the environment when using both the diegetic HUD when in comparison with the non-diegetic HUD.

- **Do you have any further comments concerning the HUD?** Even though User A experienced a more pleasant and less stressful playthrough with the diegetic HUD he insisted that a combination of the two displays should be used. The suggestion was to surround the player with only the most necessary non-diegetic HUD as it can convey rudimentary information all the time and the rest of the HUD can be placed in a diegetic context. This way you don't have a large amount of non-diegtic display items obstructing the players experience and might lead to a less stressful experience.

Symptom	Severity
General Discomfort	Moderate
Fatigue	Slight
Headache	None
Eye Strain	Slight
Difficulty focusing	None
Salivation Increasing	None
Sweating	None
Nausea	Slight
Difficulty concentrating	None
Fullness of Head	None
Blurred Vision	Slight
Dizziness with eyes open	None
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.27: User B's SSQ results for the Non-Diegetic HUD

Symptom	Severity
General Discomfort	Slight
Fatigue	None
Headache	None
Eye Strain	Slight
Difficulty focusing	None
Salivation Increasing	None
Sweating	None
Nausea	Slight
Difficulty concentrating	None
Fullness of Head	None
Blurred Vision	None
Dizziness with eyes open	None
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.28: User's B's results for the Diegetic HUD

6.12 User 'B'

Based on the results of the pre procedure survey, User B is a 26 year old male working as an IT consultant. Due to the nature of his job his computer usage is 9 hours a day at least during the weekdays. Playing games is a common occurrence for him as it his hobby. However before this study he has not had the chance to try out a Virtual Reality setting or device. The user also stated that he rarely experienced motion sickness of any sort. This User was unaware of the different types of HUD being explored so it was clarified and explained to him with examples

The SSQ results of User A are illustrated in Figure 6.27 and 6.28.

Being a consistent gamer, User B got accustomed to the controls with quite ease. However, since this was his first experience being in a Virtual Reality setting it took some time for him to get used to this new environment and get his bearings right.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?** After completing his experience with the virtual environment User B rated the non-diegetic HUD as 2 labelling them as 'annoyingly' distracting. After discussion on this point it was concluded that the reason for User B branding this display item with such a low rating was that since he was a regular gamer he did not need to feel the need to have the HUD information being constantly being displayed to him.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?** Based on his experience, User Arturo allotted the value of 8 to the diegtic HUD. The reason for this selection is partly based on his experience with the non-diegetic HUD. Since his experience with them was irksome this diegetic approach was quite a refreshing change. Without the non-diegtic diplay elements obstructing his view he could appreciate the game more and when he felt the need he could look at the diegetic display elements the gather the information.

- **Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.** During his flight around the virtual environment did experience the symptoms of cybersickness. However, in his experience the difference between the associated cybersickness with the diegetic and non-diegetic HUD was was quite considerable with his favor also going to digetic HUD.

- **Do you have any further comments concerning the HUD?** No further comments or suggestions were provided by User B regarding the HUD.

6.13 User ’C’

Based on the results of the pre procedure survey, User C is a 25 year old male currently engaged in his last years of Masters in Computer Science at the University of Gothenburg. He is also working as an IT Consultant after school hours. Due to the nature of his studies and work his computer usage consists of at least 10 hours a day during the week. Playing games is a common activity for him but something that he does not engage in daily. He divulges in games when the load of study or work is less. User C was well aware of the HTC Vive since he had used it in a project a couple of years ago. This User was unaware of the different types of HUD being explored so it was clarified and explained to him with examples.

The SSQ results of User A are illustrated in Figure 6.29 and 6.30.

Being a regular gamer and used to the HTC Vive, User C required no help or assistance in applying the headset, getting used to the environment and to the controls of the plane.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?** After gliding around the virtual environment, User C decided to give the non-diegetic a value of 3. User C considered these HUD quite useful, especially the attitude indicator as it helped him during the maneuvering of the plane around the obstacles. However, User C did feel a fewer number of HUD could have been used.

Symptom	Severity
General Discomfort	Moderate
Fatigue	Slight
Headache	Slight
Eye Strain	Slight
Difficulty focusing	Moderate
Salivation Increasing	None
Sweating	None
Nausea	Slight
Difficulty concentrating	Slight
Fullness of Head	Moderate
Blurred Vision	Slight
Dizziness with eyes open	Moderate
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.29: User C's SSQ results for the Non-Diegetic HUD

Symptom	Severity
General Discomfort	Slight
Fatigue	Slight
Headache	None
Eye Strain	Slight
Difficulty focusing	Slight
Salivation Increasing	None
Sweating	None
Nausea	None
Difficulty concentrating	None
Fullness of Head	Slight
Blurred Vision	Slight
Dizziness with eyes open	Slight
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.30: User C's SSQ results for the Diegetic HUD

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?** Based on his experience, User C gave the value of 4 to the diegtic HUD. The User commented this type of HUD provided a more realistic feel to a actual cockpit. However, the reason for not giving even a higher score on the helpful scale is that he had to switch between looking at the cockpit and then on the windshield to get his bearings and alignment right.

- **Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.** Unlike User B's experience, User C experienced a slight difference between the associated cybersickness with the diegetic and non-diegetic HUD with his favor also going to digetic HUD.

- **Do you have any further comments concerning the HUD?** User C felt there were a great degree of display elements for the non-diegetic HUD. His suggestion was to limit them to either one or two rudimentary elements such as the attitude indicator and the altimeter.

6.14 User 'D'

As established from the answers of the pre procedure survey, User D is a 27 year old male currently working as software developer. Due to the nature of his work his

Symptom	Severity
General Discomfort	Moderate
Fatigue	Moderate
Headache	Moderate
Eye Strain	Moderate
Difficulty focusing	Slight
Salivation Increasing	None
Sweating	None
Nausea	Moderate
Difficulty concentrating	Moderate
Fullness of Head	Slight
Blurred Vision	Slight
Dizziness with eyes open	Moderate
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.31: User D's SSQ results for the Non-Diegetic HUD

Symptom	Severity
General Discomfort	Slight
Fatigue	Slight
Headache	Slight
Eye Strain	Slight
Difficulty focusing	None
Salivation Increasing	None
Sweating	None
Nausea	Slight
Difficulty concentrating	Slight
Fullness of Head	None
Blurred Vision	Slight
Dizziness with eyes open	Slight
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.32: User C's SSQ results for the Diegetic HUD

computer usage takes up almost 10 to 11 hours a day. While not a regular gamer, User D identified himself as a casual gamer. The user had once tried a Virtual Reality device once before when trying out a particular university project. The device he used was an Occulus Rift. This User was also unaware of the different types of HUD being explored so it was clarified and explained to him with examples.

The SSQ results of User A are illustrated in Figure 6.31 and 6.32.

Being a casual gamer but a novice Virtual Reality user, User D faced some difficulties in getting used to the controls of the plane and maneuvering it around the environment. After a couple of failed attempts, assistance was provided and the maneuvering of the plane was controlled by me while the user observed the virtual environment with the different types of HUD.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?** Based on his experience after flying around the vitual environment, User D assigned the value of 4 to the non-diegetic HUD. The presence of the non-diegetic while very helpful to the user was also slightly annoying at the same time especially when trying to view the environment from the left and right windows of the cockpit.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?** Based on his experience with the diegetic HUD, User C gave the value of 2 to the diegtic HUD. The User commented this type of HUD provided a more pleasent experience and also gave more of an opportunity to view the virtual environment especially the obstructions.

- **Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.** Based on his experience, User D experienced a considerable difference between the amount of cybersickness felt with the different types of HUD. The presence of cybersickness was significantly more in the non-diegtic HUD then the diegetic HUD.

- **Do you have any further comments concerning the HUD?** While User D did not find the presence of the non-diegetic display elements particularly annoying, he did suggest placing them in a different manner. His advice was to place half of the display elements on top of the screen and half of them at the bottom of the screen to cause less obstruction of view.

6.15 User 'E'

Based on the results from the pre procedure survey, User E is a 26 year old female currently doing her masters in Computer Science from Chalmers University of Technology. Due to the nature of her studies her computer usage comprises at least half a day during the week. Games are something that she used to engage in regularly when younger but as time passed the usage has decreased to the degree she will play games maybe a few times a month. While aware of the different Virtual Reality devices this was her first time actually using one. Because of taking the Game Research course previously she was aware of the difference between the diegetic and non-diegetic HUD and required no explanation.

The SSQ results of User A are illustrated in Figure 6.33 and 6.34.

Being a novice gamer, User E required some assistance and practice in getting used to the control and maneuvering of the plane. However, she insisted in flying the plane herself. After several flight sessions around the virtual environment when she was comfortable enough she proceeded to complete the task herself.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?** Based on her experience after gliding around the vitual environment, User e assigned the value of 2 to the non-diegetic HUD. User E found the presence of the non-diegetic HUD extremely annoying and it took away from her experience.

- **On a scale of 1-10 with 1 being very distracting and 10 being extremely helpful, how useful would you consider the diegetic heads-up display (HUD)?** After her experience with the non-diegetic HUD, User E

Symptom	Severity
General Discomfort	Moderate
Fatigue	Slight
Headache	Slight
Eye Strain	Moderate
Difficulty focusing	Moderate
Salivation Increasing	None
Sweating	None
Nausea	None
Difficulty concentrating	Slight
Fullness of Head	Slight
Blurred Vision	Slight
Dizziness with eyes open	Moderate
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.33: User E's SSQ results for the Non-Diegetic HUD

Symptom	Severity
General Discomfort	Slight
Fatigue	Slight
Headache	None
Eye Strain	Slight
Difficulty focusing	Slight
Salivation Increasing	None
Sweating	None
Nausea	None
Difficulty concentrating	None
Fullness of Head	Slight
Blurred Vision	Slight
Dizziness with eyes open	Slight
Dizziness with eyes closed	None
Vertigo	None
Stomach awarness	None
Burping	None

Figure 6.34: User E's SSQ results for the Diegetic HUD

gave the number 8 to the diegetic HUD. This type of display element did not obstruct her view and helped her more in identifying the different objects of the screen especially the obstacles.

- **Based on your experience would you say that you experienced the feeling of cybersickness with one HUD more then the other? If so, can you please state by how much.** Similar to User D's experience, User E also felt a considerable difference between the quantity of cybersickness felt with the different types of HUD. The presence of cybersickness was significantly increased in the non-diegtic HUD then the diegetic HUD.

- **Do you have any further comments concerning the HUD?** User E was not a big advocate of the non-diegetic HUD as it provided an obstruction to the rest of the virtual environment. She felt more in sync with the diegetic HUD. However, a slight suggestion was made to improve its appearance to make it more appealing and noticeable to the user.

7
Results

In this chapter the results of the work have been presented in two sections. The first section is the result of the execution process, the outcome of which is the game prototype intended for this thesis. An overview is provided of the final version of the playable prototype of the game that was designed and implemented to explore the solution space of the research question. The second section is aimed at presenting the a summary of the results obtained from the playtest results followed by the guidelines from the potential varying effects on cybersickness with the presence of diegetic and non-diegtic HUD.

7.1 Game Prototype

The culmination of the technical part of the execution process, resulted in the game prototype envisioned, by combining the different sections of this process. The setting of the game, tentatively titled "Smokejumpers", is in a small airport nestled within a small valley.

The prototype was commenced, with the player or the pilot within the context of the game idea, sitting in the cockpit of the plane as illustrated in Figure 7.1. The seated position of the player within the cockpit is to mask the actual player wearing sitting in chair wearing the HTC Vive headset. From this position the player can view the environment around him which includes the airport and the valley encompassing it. The player can also use this opportunity to observe the different types of HUD (diegetic and non-diegetic). The prototype allows the player to switch between the different types of HUD, so that they can focus on each type separately.

The plane can begin takeoff by pressing down on the thrust lever. The thrust provides acceleration to the plane and it slowly gains speed along the runway. The amount of thrust applied can be visualized on the thrust HUD as illustrated in Figure 7.2. The acceleration of the plane is visualized by the speed with which the propellers rotate as it uses the acceleration to calculate the revolution per minute (rpm). Similarly, the deceleration of the plane can be achieved by pressing up on the thrust lever which again can be visualized on the thrust HUD and the deceleration of the propeller.

Once the plane gains enough acceleration, it slowly starts to lift up and eventually

Figure 7.1: The start setting of the prototype

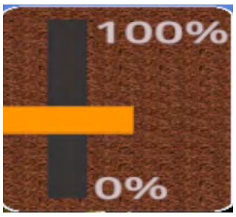

Figure 7.2: The thrust applied visualized on the thrust lever HUD

glides into the air. Once in the air the plane can be maneuvered around the environment either by pitching, rolling or a combination of both. The initial area after the plane takes off is open and contains no obstructions so the player can utilize this area to learn how to steer the plane as illustrated in Figure 7.4. Once comfortable with the controls, the player is directed towards the break in the mountains of the valley beyond which contains the destination to be reached by the player.

The break in the mountains of the valley within the virtual environment is demonstrated in Figure 7.4. Between this break and the final destination are a set of obstructions in the form of vertical walls. Theses obstructions are placed in dif-

Figure 7.3: The initial area within the environment of the prototype

Figure 7.4: Break in the valley

ferent position along the way. The purpose of these obstructions is to compel the player to steer the plane in a erratic manner as it was observed in the initial testing that this was when cybersickness was experienced most. While avoiding the obstructions and on their way the to the final destination, the players could either switch between the different types of HUD during flight or they could have one type of HUD throughout one playtest session and then have another playtest session with the other type of HUD. This selection is based on the players decision and in order to restart the second playtest session, the game needs to be restarted manually.

7.2 Playtest Results

Considering the results obtained from the Simulator Sickness Questionnaire and the post procedure survey, four out of five users reported a definite difference observed associated with the different types of HUD. Based on User A's observations there was no contrast to the amount or symptoms of cybersickness felt. However, out of these four users who did experience a dissimilarity with the cybersickness there was a difference of opinion on the amount of with which it was experienced. Out of these four users, three reported a considerable variation in the amount of cybersickness experienced while according to the remaining user D's experience the variation was diminutive.

First considering the results from the Simulator Sickness Questionnaire for all users it can be concluded that with the virtual environment created none experienced the symptoms of Sweating, Salivation increasing, Dizziness with eyes closed, Vertigo, Stomach awareness and Burping with both types of the HUD. Except User A's results, also noticeable is a difference in the amount of each symptom experienced with the different types of HUD by the rest of the users. This provides more evidence to the fact that for some users a difference or variation does exist. Considering and comparing the individual symptoms for the non-diegetic HUD for the Users B to E it can be seen that a moderate amount of General Discomfort is rampant. Also effecting the experience was the presence of fatigue in the amount ranging from slight to moderate. Except User B the rest of the users also faced slight to moderate difficulties in focusing along with slight blurred vision. In comparison to this it can be observed that within the results of the diegetic HUD for Users B to E that either the symptoms experienced is mostly slight or none when compared with its non-diegetic counter part.

7.2.1 Guidlines

Due to the ongoing corona pandemic the number of user tests that were originally planned to be conducted had to be reduced. Due to this reduction, I believe it slightly effected the results in regards to gathering more people to test out the hypothesis. However regardless, with the users that were able to attend the testing session useful information and insight was gathered. As mentioned in the beginning of this paper this thesis set out to explore and possibly answer the following question:

Which guidelines can be drawn from the potential varying effects on Cybersickness with the presence of non-diegetic and/or diegetic HUD displays?

In the following the different guidelines and considerations have been stated that have been formulated from the findings of the thesis, which should help and guide game designers to make informed decisions regarding the choice of HUD they apply in a VR game.

The amount of Cybersickness experienced with Diegetic elements is less than its non-diegetic counterpart: Based on the results of the playtest sessions and as demonstrated by the SSQ results of the users B, C, D and E in section 6.12, 6.13, 6.14 and 6.15, it can be assumed that the amount of cybersickness experienced with diegetic elements is less when compared with its non-diegetic counterpart. If for e.g. a VR game is being designed that involves fast or erratic movement, it is better to incorporate diegetic HUD elements to counter the effects of cybersickness.

When employing non-diegetic HUD reduce the number of design elements to one or two rudimentary HUD: Based on the feedback and impressions from the test users of the study most of them were not the biggest advocates of the non-diegetic approach. However, if for the design of the game the non-diegetic HUD is to be incorporated, several suggestions were discussed. One suggestion common with several of the users, was to limit the non-diegetic display elements to one or two elements. With less non-diegtic elements surrounding the player's view less are the chances of them getting annoyed.

Place the diegetic HUD in a clear and visible location to the player: Based on the discussion with the test players during the post procedure interview it was felt one of the reasons that contributed to the diegetic approach being the preferred HUD type is because it was easily visible within the field of view (fov) of the player. Unlike the non-diegtic HUD that followed the players gaze, the diegetic approach avoided that and was still well within the fov of the player. Since the player was within a cockpit, the decision to place the HUD on the cockpit panel was obvious since it fit within the context and "fiction" of the game satisfying Chalmers[] work as illustrated in Figure[]. For designers deciding to use diegetic HUD it is very important to choose an accessible and easily visible location to set the diegetic HUD. Placing the HUD in an obscured or an unnoticeable location, that requires the player to change is view frequently from one place to another can be annoying for the player and may also prove to be counter productive in tackling the symptoms of cybersickness.

Changing the order of the placement of non-diegetic HUD: The current order of placement of the non-diegetic HUD is in accordance to the work of Caroux and Isbister[11]. According to their work the important HUD for a first person perspective game are placed on the left, middle and right bottom panel of the screen. For the purpose of the game prototype the HUD consisted of the basic flight instruments of a plane, and all of them were made visible to the player in order to make a more realistic flying simulator. Placing an increased amount of HUD in front of the player's view certainly placed a role towards the dislike of the non-diegetic HUD for the test players as discusses in the second guideline above. However, based on discussion with a couple of test players during the post procedure survey, there is a belief that rearranging the HUD to be placed in a manner that was less obstructive to the player's view could lead towards a more pleasant experience and maybe even counter the effects of cybersickness. However, there are not any tests or results to confirm that.

8
Discussion

In this chapter the outcome of the thesis is discussed. To begin with reflection is presented regarding the guidelines presented in chapter 7.2.1, followed by reflections on diegetic and non-diegetic HUD. This chapter also includes a section on the execution process and the changes that followed. After that discussions are presented regarding the generalizability of this study. Finally, discussions are presented regarding the ethical aspects of the study.

8.1 Guidlines

The culmination of the design, development and testing phases within the execution chapter resulted in the formulation of a set of guidelines. These guidelines are based upon personal experience, related theory and the playtest sessions conducted. The guidelines formulated are not set in stone and are better used as a set of considerations for VR enthusiasts and designers. These set of guidelines provide information regarding the resulting consequences of using each of the different type of HUD. These guidelines present information regarding both diegetic and non-diegetic HUD. Yes, based on the results of this thesis the preferred approach is the diegetic HUD. However, based on the playtest sessions and discussions with the test players, the guidlines provide guidance on how the non-diegtic HUD can be approached if necessary. With these guidelines the designers of the VR experience can make a more well informed and knowledgeable decision when choosing the HUD type for their VR experience.

8.1.1 Non-diegetic HUD

Moving on to the results obtained from the post procedure and the discussions afterwards, there were varying opinions and suggestions for both the non-diegetic and diegetic HUD. First considering the non-diegetic HUD, User B and User E found the presence of these display elements extremely annoying while the rest of the users were not the biggest of advocates either. To counter this several suggestions and opinions were put forward. One suggestion put forward by User D was to rearrange the placement of the HUD. Based on this suggestion as an impromptu test with the same user the display elements were rearranged as he instructed and another flight around the virtual environment was taken. However, no noticeable differences could be discerned by rearranging the elements.

Another suggestion provided by User C was to limit the number of display elemets of the non-diegetic nature to one or two. However, it was felt that already only the most basic and rudimentary flight instruments[89] were being employed that comprise of the cockpit. Atleast in terms of the context of the game this did not feel valid.

8.1.2 Diegetic HUD

Moving on to the diegetic HUD it is safe to assume based on the results and the testers opinion that people enjoyed this more when compared with its non-diegetic counter part. The first suggestion was received by User A. His proposal was to use a combination of both HUD design structures i.e. Diegetic and Non-Diegetic. After discussion his idea was t use at most two of the most important flight instruments and display them to the user in the non-diegetic format. This way the user will always be aware of the most important information at all times. The rest of the display elements can be displayed in the diegetic format. The user can gather the information provided by these HUD whenever he feels necessary. This was a certainly an interesting suggestion. One that can be explored more thoroughly either as an extension or part of future work.

8.2 Execution Discussion and Planning Changes

As discussed in Chapter 6 after the brainstorming process had been finalized, the result of this process included two phases: The initial phase was to be the player aka the firefighter getting in the plane and flying towards the blazing fires. Within this phase the player would be situated within the cockpit surrounded by both the diegetic and non-diegetic HUD. And the second phase would consist of the player aka the firefighter being re situated in the forest alone without the plane with the fires surrounding him. Within this phase the player would be equipped with thrusters which can be both used for flying to the blazing location. The motivation behind this idea was that this environment completely devoid of anything (the HUD and the cockpit) could be utilized to verify if the presence of cybersickness in this environment against the one with the presence HUD and cockpit was any different and if so some conclussion could be drawn to the point that maybe having nothing surrounding the player is ultimately better.

This second phase was constructed and implemented as initially planned. Basic thrusters were created using Blender. Once the thrusters were in place, they were programmed to be situated on the left and right vive controllers respectively. Using the triggers on the vive controllers a force was created on the thrusters using which the players could maneuver themselves within the virtual environment as illustrated in Figure 8.1. The players would have to point the thrusters in the direction opposite to which they desired to move and then trigger the thrust by pressing the trigger button. A small gameplay was also created where fires were situated in random locations around the virtual environment and the players were tasked with flying

Figure 8.1: Thrusters firing in the direction of motion from the Vive Controllers

to these fires using the thrusters. Once near the fire they had to extinguish the fire by firing a water stream as demonstrated in Figure 8.2. The water stream was generated and fired by pressing on the trackpad of the vive controllers.

However, after conducting some playtest sessions within the second phase of the project it was felt that this idea did not exactly fit the context of the current study. Keeping the research question mentioned earlier in Chapter 1, it was felt the first phase was sufficient enough to fulfill the research question's requirements. Since the aim is to observe if the presence of non diegetic or diegetic HUD displays effect the ratio of cybersickness in virtual reality, it was felt this study was being fulfilled within the first phase. This second phase of the project contributes more towards and fits the context of the game idea: SmokeJumpers. However, in terms of the research question the first phase of the project satisfies the condition to conduct the study.

Another change encountered was in regards to the testing phase. Due to the corona virus pandemic several changes took place within the execution period. Originally it was planned to conduct the test sessions within the studio in the University premises since the computer system and the virtual reality equipment was present there. However, since due to the epidemic the University and all of its faculties were to shut down the only alternative available was to move the equipment to the apartment. The reason as to why this move presented a complication was because of two reasons. The first reason, the studio in the University had ample space to place the HTC Vive sensors and the equipment in itself. This space was not present in the apartment and it became very cluttered. Because of these obstructions at times it was difficult to test within the virtual environment.

The second issue that this move created was a reluctance from the part of potential testers to venture into the apartment which ultimately led to a reduction in the

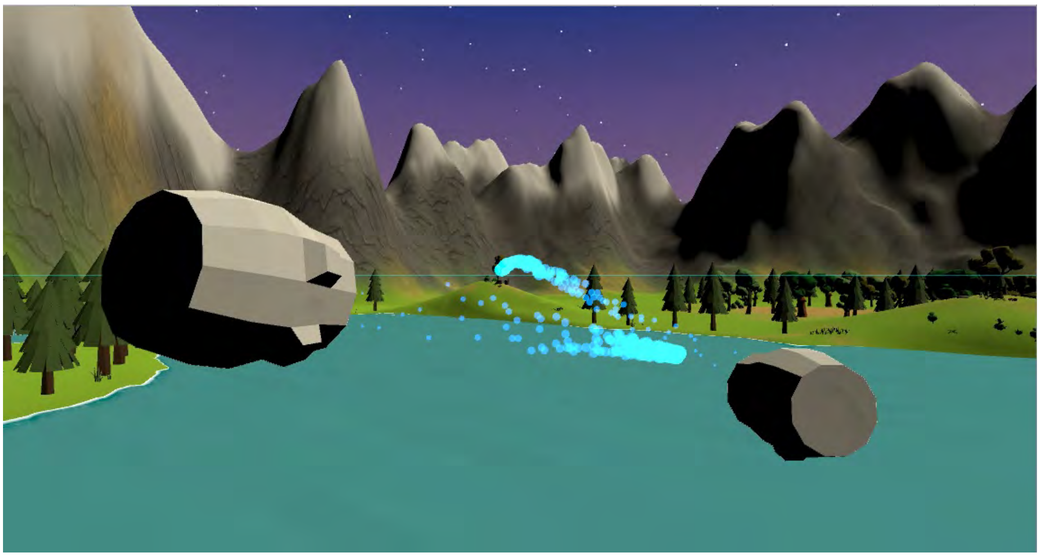

Figure 8.2: Jet of water expelled from the thrusters when the trackpad is pressed from the Vive controllers

number of testers as originally planned. The hesitance on the part of the testers was understandable because of the situation the Covid 19 virus created and social distancing was encouraged.

8.3 Generalizability

Major corporations from all fields of work are investing millions of dollars into virtual reality technology. The possibilities of this technology are endless, but with the great development of this new technology new challenges also appear. Video games have always been a form of escapism for gamers. Even before the advent virtual reality headsets, the design of the HUD and the user interface (UI) converse with the game's conceptual world in order to make that link stronger.

A classical example of this mismatch of illusion created by using non-diegetic display elements is that of Skyrim VR[110] as illustrated in Figure 8.4. By looking at the figure in this game there is a high probability the user in the game can easily become confused as where he is or why is he floating in the sky.[111]

While various work has been done in deciphering the issue of cybersickness in the field of virtual reality the purpose of this study is not trying to solve any concrete problem but rather highlight that there exists consequences and varying amounts of cybersickness when selecting different types (diegetic and non-diegetic) of HUD for games. With the recent in growth of virtual reality games upcoming and under production, this study should provide a set of considerations and not strict rules regarding the use of non-diegetic HUD especially with virtual reality games that incorporate high velocity and rapid movement around the virtual environment for e.g. Iron Man VR[112].

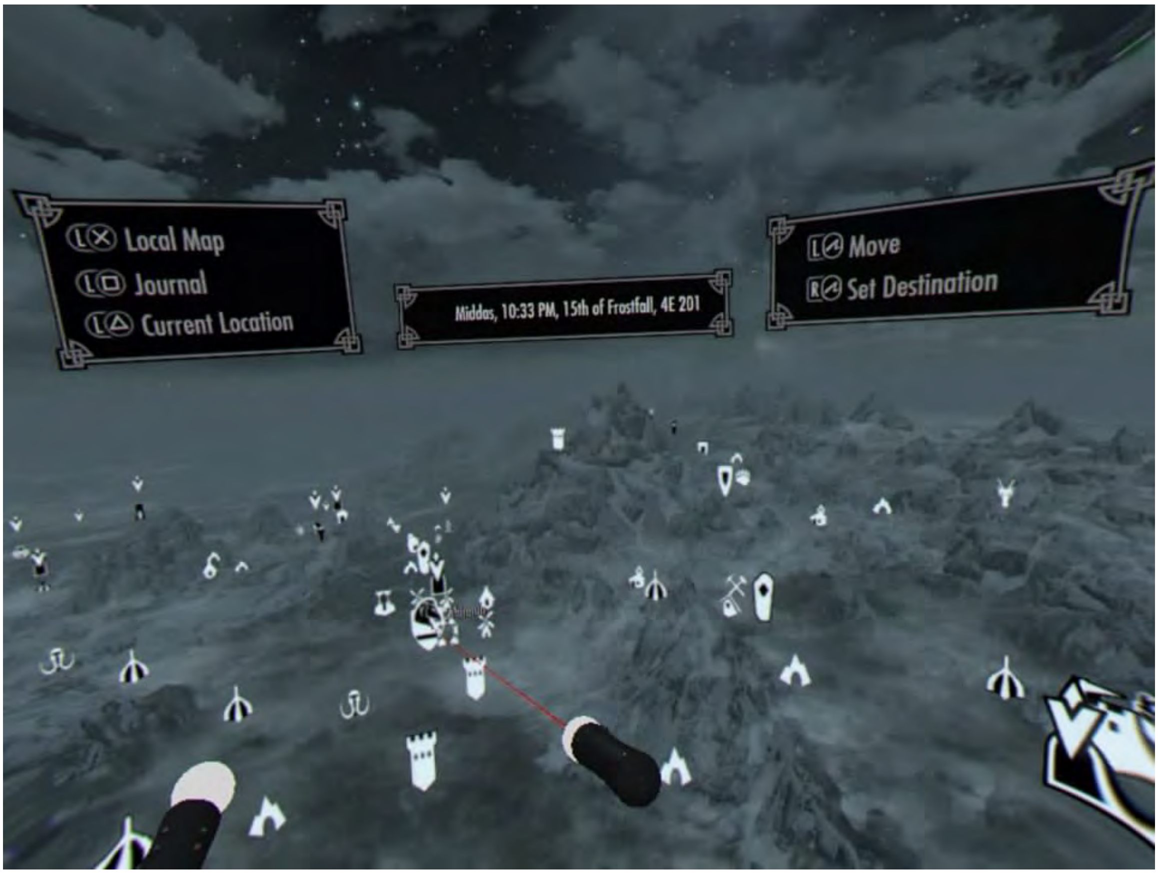

Figure 8.3: Skyrim VR game map using non-diegetic HUD and UI elements.[16]

Figure 8.4: The use of non-diegetic HUD in the upcoming Iron Man VR game.[17]

8.4 Ethics

As discussed previously in the methodology section 4.7, it was discussed wether if the participants would be video recorded during their trial in the virtual environment, with their consent of course. However, it was felt that recording the individuals behavior while they were assessing the virtual environment as it provided no additional value to the purposes of the study. The observations from the test users would suffice for the purposes of this study. The participants that did take place in the tests in order to protect their privacy and for maintaining anonymity their names have been omitted and replaced by characters in the Results chapter of the document.

In order to avoid unnecessary risk of exposure the number of participants involved originally had to be reduced. All participants that eventually did take part in the study were from the same apartment complex where the apartment was located in an attempt to reduce outside exposure. Also before their participation it was ensured from all participants if they were comfortable and willing to engage in the tests.

9 Conclusion

The aim of this study was to explore the potential varying effects of the cybersickness experienced with the diegetic and non-diegtic HUD. Based on these experiences formulate a set of guidelines that could help designers in regards to their choice of HUD that could even help them counter the effects of cybersickness. As mentioned in the beginning of this paper this thesis set out to explore and possibly answer the following question:

Which guidelines can be drawn from the potential varying effects on Cybersickness with the presence of non-diegetic and/or diegetic HUD displays?

In the points below I have decompressed the research question into smaller sections and try to relate it with the results of the study to draw conclusions if ultimately this study address this query.

- **Is there a presence of cybersickness with either Diegetic or Non Diegetic HUD displays?** Based on the result from the users test sessions all the users involved attested that they felt presence of cybersickness with both Diegetic and Non-diegetic HUD displays. Based on this outcome I believe it is safe to assume that there is a high possibility of encountering cybersickness with either of the display types.

- **Does the effects of cybersickness vary when comparing virtual reality with either Diegetic HUD or Non-diegetic display HUD?** After conducting the user test session four out of five of the users attesting that there certainly was a difference in the effects of cybersickness when comparing their experiences with the different types of HUD. Out of these fours users, three of them observed considerable varying amounts of cybersickness when making comparisons. However, all users felt the presence of cybersickness was less with Diegetic HUD. Based on these users observations it is safe to assume that the symptoms of cybersickness are less when Diegetic HUD are employed but to decipher by how much I believe a larger number of user tests are required to make any deductions.

- **Are one of the two types of HUD more helpful or distracting then the other?** While this statement is not explicitly mentioned in the research question of this paper, based on the insight and observations provided by the test users, I felt important to include it. Most of the users reported the presence of the non-diegetic HUD from mildly to severely annoying. So whenver this type of display is being incorporated in any virtual reality game one must be careful and aware of the potential consequences.

- **The set of the guidelines** Based on the findings mentioned above, a set of guidelines were formulated discussed in chapter 7.2.1, which can hopefully guide VR designers help making a more informed decision and and be aware of the pros and cons corresponding with each HUD type.

9.1 Future Work

There are several directions or possibilities that comes to my mind for further future work within this study.

The first of these directions is moving these research from a qualitative approach to a quantitative study. With a large number of users it will be more easy to conclude if there are varying effects of the presence of cybersickness in virtual reality with diegetic and non-diegetic HUD. And from this it will be possible to gauge out the ratio of this variation.

Another interesting direction I foresee this study taking is observing if a combination of the diegetic and non-diegetic HUD displays work better or have even have less varying effects of cybersickness when compared with them separately.

As virtual reality technology is rapidly evolving for example the HTC Vive Pro Eye[113] it will be interesting to study if these new technologies will have any effect on the the research of this thesis.

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A

Appendix

Pre Procedure Survey

1. What gender do you identify as?
2. What is your current age?
3. What is your current age?
4. How often do you use a computer?
5. What are your main reason for using a computer?
6. How often do you play video games?
7. Do you have any prior experience with any sort of Virtual Reality device?
8. Are you aware of the differences between diegetic and non-diegetc HUD elements?
9. Do you easily get motion sickness? If so, please explain

B

Appendix

Simulator Sickness Questionnaire
Select how much each symptom affected you

1. General discomfort None Slight Moderate Severe
2. Fatigue None Slight Moderate Severe
3. Headache None Slight Moderate Severe
4. Eye Strain None Slight Moderate Severe
5. Difficulty focusing None Slight Moderate Severe
6. Salivation increase None Slight Moderate Severe
7. *Fullness of head None Slight Moderate Severe
8. Blurred vision None Slight Moderate Severe
9. Dizziness with eyes open None Slight Moderate Severe
10. Dizziness with eyes closed None Slight Moderate Severe
11. **Vertigo None Slight Moderate Severe
12. ***Stomach awareness None Slight Moderate Severe
13. Burping None Slight Moderate Severe

* Fullness of the head can also be described as a perceived buildup of pressure in the head making it feel "full."
** Vertigo is experienced as loss of orientation with respect to vertical upright.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

C

Appendix

Post Procedure Survey

1. On a scale of 1-10 with 1 being very distracting and 10 being ex-tremely helpful, how useful would you consider the non-diegetic heads-up display (HUD)?

2. On a scale of 1-10 with 1 being very distracting and 10 being ex-tremely helpful, how useful would you consider the diegetic heads-updisplay (HUD)?

3. Based on your experience would you say that you experienced thefeeling of cybersickness with one HUD more then the other? If so,can you please state by how much.

4. Do you have any further comments concerning the HUD