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THESIS

**PROOF-OF-CONCEPT VIRTUAL REALITY
PARACHUTE TRAINING SIMULATOR**

by

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June 2023

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**PROOF-OF-CONCEPT VIRTUAL REALITY PARACHUTE TRAINING
SIMULATOR**

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ABSTRACT

The miscalculation of the height during the landing phase of the parachute jump is found to be a frequent cause of physical injuries among parachute jumpers and paratroopers. Providing trainees with the opportunity to practice parachute jumps in different terrains and acquire good skills when estimating the height (altitude) is essential in reducing, if not even eliminating, future injuries. This thesis research uses virtual reality technology to create a complementary training solution for military parachute training. The proof-of-concept training system uses immersive commercial off-the-shelf (COTS) virtual reality headset and passive haptics technology. This system aims to be used as a part-task trainer; the targeted elements of human performance consist of improvements in situational awareness and human perceptual skills when evaluating heights during parachute jumping. The results of the user study suggest that, much like with the evaluation of horizontal distances, people make systematic errors when evaluating vertical distances. A real-time, interactive virtual environment and training scenarios presented to the trainees inside the virtual reality headset have the potential to help improve trainees' situational awareness and allow them to practice evaluating the heights more precisely during the landing phase. As a result, this approach may reduce the likelihood of accidents, increase training, and positively affect the level of units' operational readiness.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFF	accelerated free fall
API	application programming interface
AR	augmented reality
BAC	basic airborne course
CBS	computer based system
COTS	commercial off-the-shelf
CSV	comma separated values
DOD	Department of Defense
FOV	field of view
GUI	graphical user interface
Kn	kilo Newton
HMD	helmet mounted display
HDRP	high-definition render pipeline
IDE	integrated development environment
IVR	immersive virtual reality
IRB	Institutional Review Board
MR	mixed reality
NPS	Naval Postgraduate School
OS	operating system
PC	personal computer
ROS	research operations station
SA	situational awareness
SDK	software development kit
SSQ	simulator sickness questionnaire
SUS	system usability scale
UI	user interface
USAIS	United States Army Infantry School

UX	user experience
VE	virtual environment
VR	virtual reality
VR-PTS	virtual reality parachute trainer system
XR	extended reality

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I. INTRODUCTION

A. RESEARCH DOMAIN

The reduced costs of hardware and software, as well as the advances in user interfaces, have allowed the deployment and use of computer-based systems (CBS) by many users. In particular, the integration and miniaturization of components across the different generations of computers have also driven costs of technology down; rapid progression in development started as early as the invention of transistors in the second generation and accelerated to integrated circuits (IC) and the microprocessor in the third and fourth generations, respectively.

One subset of the CBS is the virtual reality (VR) systems which enable any user to experience fully immersive environments—the environments that allow users to be surrounded by simulated sensory stimuli. According to the Future Visual webpage, effective training should provide an immersive learning experience that mimics real-life situations and work challenges. This type of training offers a risk-free environment for employees to practice and learn by doing. Additionally, trainees are more likely to retain the skills they acquire through this training method, resulting in increased productivity when applied in the workplace (VR Solutions for Businesses, 2023).

Moreover, the military domain has been supporting efforts to make significant advances in science and technology; the results have benefited both military and civilian domains. Computer systems have started supporting military needs on the battlefield (operations) as well as in the training domain. Similarly, VR technology has become more common not only for military training in general, but also for parachuting training.

Parachute trainers allow users to experience situations and acquire skills before conducting actual jumps. Being that the acts of parachuting can result in injuries and even loss of life, getting necessary skills before actual jumps is very important. Ideally, VR technology has the potential to support the training of skills that otherwise would include human subjects operating in dangerous activities such as parachuting and high-risk environments. Further, this technology has a high potential to afford not only cheaper but

safer training than experiencing real-world tasks and situations. The downside, however, is dealing with a lower level of realism at times, which may or may not be prohibitive for effective human use.

B. RESEARCH PROBLEM AND MOTIVATION

Training Circular (TC) 3-21.220 document “provides all Department of Defense (DOD) airborne personnel with techniques and training guidelines to maintain an airborne force (USAIS, 2018).” There are two main locations where U.S. military personnel undergo parachute training: the United States Army Airborne School, commonly known as the “Jump School,” which conducts the Basic Airborne Course for all services of the DOD, and the U.S. Military Free-Fall School.

Having well-trained troops is an important goal in every military force. Therefore, it is understandable that considerable resources, including time, money, space, and personnel, are spent on training to have the most capable workforce to win battles. Furthermore, having well-trained troops is not an easy task; many factors must be addressed to accomplish that important task.

Needless to say, parachute training is not without challenges and areas in need of the improvement. One of the most prominent issues with current practices include the likelihood of injury when landing due to one or more of the following circumstances: not landing against the direction of the wind (if possible), flaring too high, flaring too low, or not flaring at all (Canopy Handling Manual, 2022). Furthermore, there is a big gap between the on-ground training and the actual jump. For example, the paratrooper jumps alone in the actual jump from the very beginning (at least in the military), and there is no opportunity to feel the movement when approaching the earth from the air.

Even though there are a lot of commercially available solutions consisting of simulation technology, such as those provided by the companies PARISIM or Quantum3d, the starting price of those training solutions is a significant disadvantage for the training force. Additionally, another drawback is the hidden cost of maintenance, which often cannot be readily estimated. The third obstacle is the vendor lock-in—the unintended dependence that develops on a particular vendor and the type of technology they sell. This

last point is important because other large companies (e.g., Meta, Google, Microsoft) may offer new, disruptive technology into the market that could be more effective. However, if the military is contractually attached to a particular vendor for a long period, it will not be able to take advantage of the new commercial off-the-shell solution (COTS) or technology from competitors that may have better capabilities and tools for a lower price.

To offset the prohibitive cost of large-scale training simulators, it may seem practical to purchase only a small number of simulators; that, in turn, will allow only a small number of people to train simultaneously. On the other hand, a direct benefit of a low-cost training solution is the ability of the military to acquire a higher number of those solutions and support simultaneous training of many individuals.

Finally, sometimes training in complex environments is hard to replicate. Those training situations can be overly dangerous or even impossible, so using virtual environments becomes the only viable way to train the personnel or rehearse military operations.

This thesis describes a study that aims to address one issue from the list just presented. It investigates the feasibility of developing a computer-based training system that uses immersive VR display technology and passive haptics to allow users to practice evaluation of altitude in the landing phase of the parachuting process, specifically the final approach and the flaring stages. The motivation to focus on that issue is the number of injuries that result from a lack of those skills. Namely, miscalculation of height in those phases has been found to be one the most frequent causes of physical injuries of paratroopers.

Furthermore, having affordable, low-cost VR simulators could help increase the number of people receiving that type of training. As already mentioned, the major limitations of large-scale simulators include their initial setup cost and maintenance and operational costs. Those prohibitive costs limit the number of solutions being purchased; that, in turn, dictates low throughput, which results in a limited number of people receiving the necessary training.

The current approach to parachute training is depicted in the flow chart in Figure 1.



Figure 1. Current training approach

The guiding idea in this research is to address the gap between Phases 2 and 3. The real-time, interactive virtual environment and training scenarios presented to the trainees inside the VR headset have the potential to help improve trainees’ situational awareness and allow them to practice evaluating altitudes more precisely during the landing phase (Figure 2). This approach may reduce the likelihood of accidents and increase the overall quality of the training.



Figure 2. Proposed training approach process

It is important to note that the introduction of a VR training solution is not advocated as a replacement for the current training process but as a complement to that training process.

C. RESEARCH QUESTIONS AND HYPOTHESIS

Given the problem at hand, the main research questions for this feasibility study are the following.

1. What is the feasibility of developing a low-cost prototype that employs COTS, immersive VR technology and passive haptics in support of parachute landing process?

2. To what extent does VR enhance height situational awareness for a paratrooper?

Hypotheses related to Research Question 2:

- H01: There is no difference in the subject's final landing approach height mean user estimation in VR view and the actual virtual world space height: $\mu_{VR} - \mu_{WV} = 0$.
- HA1: There is a difference in the subject's final landing approach height mean user estimation in VR view and the actual virtual world space height: $\mu_{VR} - \mu_{WV} \neq 0$.
- H02: There is no difference in the subject's flare stage height mean user estimation in VR view and the actual virtual world space height: $\mu_{VR} - \mu_{WV} = 0$.
- HA1: There is a difference in the subject's flare height mean user estimation in VR view and the actual virtual world space height: $\mu_{VR} - \mu_{WV} \neq 0$.

The hypothesis underpinning this thesis is that it is possible to develop a low-cost, lightweight task trainer using COTS technologies in support of the height situational awareness of the parachute training process for paratroopers. The research also assesses whether it is possible for the developed task trainer to provide satisfactory technical performance in terrain fidelity and simplicity of user interface controls while generating the sensory stimuli and situational awareness needed for this type of training.

D. SCOPE

The scope of this feasibility study is to develop a prototype simulation for parachute training using low-cost COTS software and hardware. It is important to note that this thesis focuses only on situational awareness related to height at two critical points in the parachuting landing process: the final approach and the flare height. The final approach height depends on many factors, such as wind direction and speed, but a good rule of thumb is that it takes place at approximately 300 meters (1000 ft). The flaring point takes place at

5 meters (16 ft). Even though a maneuvering mechanism will be present and available to the users in the prototype, the mechanism will not have high-fidelity precision to mimic the actual aerodynamic behavior of a parachute and will not be a focus of our study.

E. METHODOLOGY

The methodology used to address all research questions is the waterfall model which is used by many in project and software management. The following activities will be executed:

Literature review and background: Review of the past research done in this domain.

Task analysis: Examination of current training approaches, different types of canopies, and factors that affect the parachuting task.

Design of the system: Evaluation and comparison of available technologies, followed by the design of the architectural framework for the novel training solution.

Prototyping: Development of a prototype system using low-cost COTS solutions.

Usability study: Design and conduct of a usability study in support of the main feasibility study and analysis of the data sets collected during that study to answer the research questions.

F. THESIS STRUCTURE

Chapter I has outlined the research domain, research questions, the scope of our study, and the methodology used for this research.

Chapter II describes background research done in the field of immersive virtual reality, passive haptics, and parachute trainers.

Chapter III presents the elements of task analysis of the parachuting process.

Chapter IV depicts the design of the prototype, system architecture, and other design considerations for the prototype.

Chapter V presents the development of the prototype training system itself.

Chapter VI presents the user study and the statistical test performed to evaluate the data collected in the experiment through statistical t-test and ANOVA.

Chapter VI summarizes the conclusion of the work and outlines directions for possible future work.

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II. BACKGROUND AND LITERATURE REVIEW

A. INTRODUCTION

This chapter reviews the state of the art of parachuting, including an overview of the history of parachute training, current solutions, and issues. It also examines the use of virtual reality for that type of training and several important topics, such as presence and situational awareness. All those topics help outline the baseline and common framework for this thesis research.

B. PARACHUTING AND VIRTUAL REALITY

Parachuting and virtual reality have different origins but through time they have converged to a common point.

1. History

Leonardo Da Vinci conceived the idea of a parachute in his writings, but Andres-Jaques Garnerin made the first parachute jump in 1797 in Paris (Soden, 2005). The use of the parachute was soon envisioned for war units, such as the Airborne forces, which are units carried by aircraft and airdropped into battle zones. These personnel are also known as paratroopers.

In the modern era, several authors have addressed the need to construct and support parachute training using computer-supported solutions. For example, the work done by Hogue and his colleagues (2001) used computational methods to model parachute systems. The work reported by Stein et al. (2003) showed that the use of VR is feasible for this kind of training.

Additionally, a study done by Butavicious et al. (2012) compared the training conducted using a simulator (a VR head mounted display (HMD)) with training that employed classroom-based instruction. Their results suggested no statistical significance between the jump accuracy, jump safety, and confidence exhibited by the trainees in either group. However, the trainees who used the VR simulator required fewer feedback corrections during the live jumps. It is worth noting that trainees in that study had very few

trials in the simulator, so it is possible that such a low number of trials could have offered less chance for skill acquisition to happen. We can only speculate about whether the results would have been better had they had more practice runs in the simulator. Finally, Hogue et al. (1991) concluded that “a parachuter simulator is an ideal tool for teaching jumpers desirable parachute handling techniques; the instructor can quickly identify a trainee’s weak points and improve them as many times as necessary” (Hogue et al., 1991, p.33.)

2. Current Solutions

Nowadays, several companies offer different solutions for training, and among them, Parasim and Armick provide complete solutions to the armed forces. The main components of these kinds of solutions include a real-time image generation module, passive hand haptics, and mechanisms for generating different scenarios. Figure 3 shows one example of a commercially available solution.



Figure 3. People training in a commercial parachute VR system. Source: Parasim Inc (2023).

3. Issues

One of the most significant VR training system issues is the small number of available systems; furthermore, these simulators are available in only a few places. Given that the volume of personnel training input is very high, using such VR technology solutions daily would require introducing multiple systems to avoid any bottlenecks. Every year the airborne school trains approximately 14,000 trainees, i.e., an average of 1,200

every month (U.S. Army Airborne School, 2023). Therefore, it is feasible to think that having at least 100 systems is necessary to simultaneously train all personnel without interfering with the subsequent training stages.

Right now, the only way to mimic how the jumper approaches the terrain for distance judgment is by performing a jump from a 250-foot free fall tower (shown in Figure 4), which is often harder for trainees than the actual jump. Moreover, there are only a few such premises, and they are available only for static line parachute training (Airborne School, 2023).



Figure 4. 250 feet-tall towers for static line parachute training. Source: Defense.gov. (2023).

Another disadvantage with this type of solution is that it can only provide one type of terrain, which is a distinct disadvantage when compared to the synthetic environment of a VR training solution that can replicate more challenging terrains. Good examples of other terrains include desert terrain, mountains, and forests with a variety of vegetation. A trainee would also need to experience different weather conditions as that may influence situational awareness and depth or distance perception when falling.

C. A SENSE OF PRESENCE IN VIRTUAL REALITY

A sense of presence in virtual reality refers to the psychological sense of "being there" or being a part of the computer-generated environment (Draper et al., 1998). A sense

of presence is essential for creating a sense of engagement with the virtual environment and acting the same way a trainee would behave in the real environment. The more present a user feels in the virtual world, the more likely he or she is to perceive the experience as real and to engage with it emotionally and cognitively (Bailenson, 2018). The responsiveness and accuracy of the tracking system also play a role in creating presence, as any delay or inconsistency in the feedback can break the illusion of presence (Sanchez-Vives & Slater, 2005).

Today, a high level of sense of presence is achieved through a combination of hardware and software solutions, including high quality scenarios. High-resolution fully immersive displays and powerful processors enable realistic graphics and physics-based simulations, while sensors and motion tracking systems record the user's motion and translate them into the virtual environment. The result is an immersive environment that can be used for a variety of applications, from gaming and entertainment to education and training.

Overall, the use of VR and the phenomena it supports (like presence) represent a powerful tool that has the potential to impact a wide range of industries. Presence refers to the user's psychological sense, while immersion is the extent to which sensory stimuli surround the user (Sadagic, 2022). Whether it is used for entertainment, education, or therapy, VR could create a sense of presence unequaled by other technologies and media. As VR continues to evolve and become more advanced, it will be interesting to see how this technology is used to shape the future.

D. PASSIVE HAPTICS

VR has become increasingly popular in recent years due to its ability to provide an immersive experience that can create an illusion of being in different environments and situations. Nonetheless, VR is and will remain only a simulation, i.e., there will always be some mismatch between the physical and virtual environment. Additionally, some sensory stimuli may be missing altogether. For example, the users may be able to see and hear things in the virtual environment; however, they may not be able to touch or feel the objects like they can in the physical world. That is where passive haptics may help.

Passive haptics, a technique available in VR, can enhance the sense of touch and presence by using physical objects (props) that have the shape and texture of the virtual objects the user is interacting with (Lombard et al., 2015). The idea behind passive haptics is that by providing a physical object, the user's brain will be tricked into thinking that the user is touching or holding the virtual object. That can enhance the sense of presence and make the VR experience feel more real.

There are several benefits to using passive haptics in VR. The main benefit is that it can enhance the user's sense of presence and make the virtual environment feel more real. That, in turn, can improve the user's overall experience and make virtual reality more engaging and effective. Passive haptics can also be a cost-effective solution to providing a sense of touch and presence in VR. Unlike active haptics, such as exoskeleton force feedback setups and gloves, passive haptics a perfect fit for what is needed, eliminating the need for additional hardware or setup.

Nevertheless, there are also limitations to using passive haptics in VR. One limitation is that the physical objects used in passive haptics may not be completely identical to the virtual objects, which could lead to a sense of dissonance. Additionally, passive haptics may not be suitable for all virtual reality applications, particularly those that require precise or detailed interactions like touching surfaces or sensing temperature.

E. DEPTH AND DISTANCE PERCEPTION IN VR

VR applications that require spatial navigation or object manipulation heavily rely on accurate depth perception to create an immersive and realistic experience. According to Jamiy and Marsh (2019) “among all the human factors in VR, depth perception is one of the most important. The perception of depth is influenced by the head-mounted display (HMD), which inevitably decreases the virtual contest's depth perception.” (p. 707). Moreover, depth perception is a crucial aspect of VR experiences, as it allows users to perceive distances and relative positions of objects in a simulated environment.

Two frames of reference are used to evaluate distance: egocentric and exocentric frame of reference. Egocentric distance refers to the perception of the distance between the observer and objects in a virtual environment from the observers' own point of view or

egocentric reference frame (Renner et al., 2013). In VR, egocentric distance is typically simulated using various cues, such as binocular disparity (the difference in the image received by each eye) and size and texture gradients (the way the size and texture change with distance). Accurately simulating egocentric distances in VR is important for creating a convincing and immersive experience. Yet, egocentric distance perception continues to be a problem in modern VR headsets (Doty & Kelly, 2021).

Humans use both monocular and binocular depth cues to evaluate depth. Depth perception in VR systems is enabled by the following techniques:

- *Stereoscopic imaging*: Stereoscopic vision is a technique used to create the illusion of depth perception by presenting slightly different images to each eye. VR headsets typically use two small displays, one for each eye, which display slightly different images that are combined by the brain to create a 3D effect (Vishwanath & Hibbard, 2013).
- *Stereoscopic vision*: The human brain can register and derive depth cues using the images acquired by each eye. The difference between the images presented to each eye is known as the interocular distance, which is typically set to match the average distance between the eyes of the user (Yu, 2020). This helps to create a realistic and immersive 3D effect in which virtual objects appear to have depth and occupy space in the same way as real-world objects. To ensure that the images presented to each eye are correctly aligned, VR headsets typically include features such as IPD (interpupillary distance) adjustment, which allows the distance between the lenses to be adjusted to match the user's individual interpupillary distance.
- *Accommodation and convergence*: Accommodation and convergence are the mechanisms by which our eyes adjust to focus on objects at different distances. In VR, the distance between the virtual objects and the user's eyes is fixed, which can lead to visual discomfort and a mismatch between

the accommodation and convergence cues. Some VR headsets include features such as eye tracking and variable focus to address these issues.

- *Texture gradients*: Texture gradients refer to the gradual changes in texture or pattern that occur as the surface of an object recedes into the distance. In VR, texture gradients can be used to create the illusion of depth by simulating the changes in texture or pattern as virtual objects move further away from the user.
- *Occlusion*: This is another monocular depth cue. The basic principle suggests that closer objects occlude objects that are further away when they are viewed along the same line of sight.

Many theories have been suggested regarding the accuracy of a user's perception of depth in VR; unfortunately, no conclusive answer has been proposed. However, according to Davide et al. (2009) "a common conclusion between all the experiments is that observers underestimate long distances in virtual environments" (p.1). This underestimation is confirmed in the studies made by Swan et al. (2007), Waller and Richardson (2008), and Thompson et al. (2011).

What causes this visual compression phenomenon is still not well understood; research has shown that "field of view (FOV) has no influence on determining depth perception" in the research made by Knapp and Loomis (2004, p. 572); moreover, other research done by Thompson (2004) concluded that "the absence of realism element in the scene coming from graphical computer-based does not influence the depth perception in VE" (p.11).

Another study made by Interrante et al. (2006), and based on the paper by Jamiy and Marsh (2019), analyzed the contrast between reality and the VE triggers VR length issues, but the results were not confirmatory. Murgia and Sharkey (2009) investigated the same topic and found that "depth estimation is not accurate no matter how the environment is, either rich or poor with depth cues" (p. 67).

F. SITUATIONAL AWARENESS

Endsley (2001) defines situational awareness as “the human perception of the elements in the environment within time and space, the comprehension of the elements, and the projection of their status in the near future” (p.1). In other words, situational awareness is the capability of filtering out all but the most important elements of one’s environment while discarding those that are not; this helps in making the appropriate decision when time and circumstances matter. Situational awareness is essential, especially when landing with a parachute at a particular speed; the act of landing is the most crucial part of the whole jumping process, and all visual input information must be used to make informed and timely decisions in this phase of the process.

Maintaining situational awareness is important in VR to ensure the safety and comfort of the user, as well as to achieve specific goals or objectives within the virtual environment. There are several factors that can affect situational awareness in VR, including the quality and responsiveness of the VR hardware, the design and layout of the virtual environment, and the user's level of experience and familiarity with VR technology. To enhance situational awareness in VR, designers and developers can incorporate features such as clear visual cues, realistic sound effects, and intuitive controls. They can also provide training and guidance to help users become more comfortable and proficient in using VR technology.

G. CYBER-SICKNESS AND OTHER VR SYMPTOMS.

Like any other technology, VR has its drawbacks. One of the significant disadvantages is cyber-sickness. Cyber-sickness is different from motion sickness, as it can occur even when the user is not physically moving but experiences a strong sensation of self-motion due to the movement simulated by visual images in VR (LaViola, 2000).

One of the theories on why that happens is the sensory conflict theory, which basically states that the brain combines the visual sensorial data to determine where the body is in space with the vestibular sensory system; when there is some disagreement or conflict, sickness symptoms will occur (Thornton & Bonato, 2013; Weech et al., 2018).

Among some other issues that may occur are eye strain, headache, disorientation, vertigo, nausea, vomiting, and finally, some form of photosensitive epilepsy, in which seizures are triggered by visual stimuli such as lights or movement of regular patterns.

H. LEVEL OF REALISM IN SYNTHETIC ENVIRONMENTS

Realistic synthetic environments (SE) are computer-generated environments that mimic real-world environments in an immersive and interactive way. These environments are created using advanced computer graphics, motion tracking, physics engines, and other technologies to simulate the sights, sounds, touch, smells, and other sensations of a real-world environment. We use various technologies to create a realistic synthetic environment; those technologies include computer graphics, 3D modeling, artificial intelligence (AI), and VR. The goal is to make the environment as close to reality as possible, with attention given to detail, lighting, sound effects, and physics. The more realistic the environment, the more immersive the experience for the user.

One of the main application domains of realistic synthetic environments is in training and simulation. VR can also be used for scientific research, allowing scientists to simulate complex systems and environments, such as the human body or the climate. Another important application of realistic synthetic environments is in entertainment. VR games and experiences can create immersive and interactive worlds that transport users to different times, places, and even fictional realities. VR movies and television shows can create immersive and engaging experiences that feel like being in the middle of the action.

One of the challenges of creating realistic synthetic environments is the need to balance realism with performance. Creating a realistic environment can require a lot of computational power, which can limit the number of users or the complexity of the environment. Another challenge is creating realistic interactions between users and the environment, such as simulating the physics of objects (animating the objects) or the behavior of crowds.

The work on realistic synthetic environments is continually progressing with advancements in technology, such as the use of photorealistic rendering, AI, and machine learning. They have numerous applications across various industries and are likely to

become more prevalent as technology continues to evolve. In conclusion, there is still not a complete understanding of all the factors that relate to presence (i.e., synthetic environments) and human performance (Ma & Kaber, 2006).

I. CHAPTER SUMMARY

In this chapter, we reviewed some important literature related to the evolution and use of VR in general. We introduced some terminology as well as some constraints related to working with VR technology. VR has been used in various fields, including military training, to provide more immersive and realistic simulations for soldiers, and parachute training is one such area where VR has been utilized.

In conclusion, VR has revolutionized how paratroopers are trained in the military, and it will be even more important in the future. Its immersive, realistic, and cost-effective nature has made it a tool for preparing paratroopers for the challenges they may face in any field. Whether it is practicing emergency procedures or navigating to a specific landing zone, VR training may provide paratroopers with the skills and confidence they need to succeed at landing. One important part of that preparation process is the correct evaluation of virtual distances and depths.

III. TASK ANALYSIS

A. INTRODUCTION

Task analysis is the study of the process that users must perform when executing any duty. Task analysis is intrinsically related to the “what and how” of a particular mission. Task analysis is, therefore, a critical part of the lifecycle of any system and the base for the future design of a system (Kirwan & Ainsworth, 1992, p. vii).

According to USAIS and the *Static Line Parachuting Techniques and Training* manual (2018) “the purpose of airborne training is to qualify personnel in the use of the parachute as a means of combat deployment. This training also develops leadership, self-confidence, and an aggressive spirit through mental and physical conditioning”. The information from the task analysis used in this thesis is based, among others, on the manual of static line parachuting techniques and training.

B. PARACHUTING PROCESS AND PHYSICS

The free fall parachuting process can be divided into several stages:

1. *Jump*: From the moment the air-trooper leaves the airplane.
2. *Free fall*: The parachute is closed so the speed increases very quickly.
3. *Canopy open*: The canopy is open and the speed decreases considerably.
4. *Maneuvering*: When the parachute is open it slows the parachuter’s speed and enables maneuvering.
5. *Final approach*: The final approach depends on many factors, like the speed and direction of the wind; it is one of the most critical phases. In an ideal parachute jump without wind, the downward speed is the same as the forward speed; in other words, the distance traveled horizontally is the same as the distance vertically. As a good rule of thumb, 300 meters is a good final approach height.

6. *Flare*: In the flare stage, the parachuter prepares for contact with the ground; once again, the height depends on a series of factors, such as the size and shape of the parachute, but a good rule of thumb is performing the flare at about 5 meters above the ground.
7. *Roll out*: Finally, when the air-trooper hits the ground, he must roll over the soil to transfer his kinematic energy over a longer amount of time, reducing the force and likelihood of injury.

1. Aerodynamics

Aerodynamics plays a central role in parachuting. The free fall diagram can be seen in Figure 5. We can tell that the two main forces are the upward vectors, which result from the lift and drag component, and the downward vector, which results from the weight and the forward inertia of the airborne individual. The drag component can be further decomposed in the skin friction and frontal area.

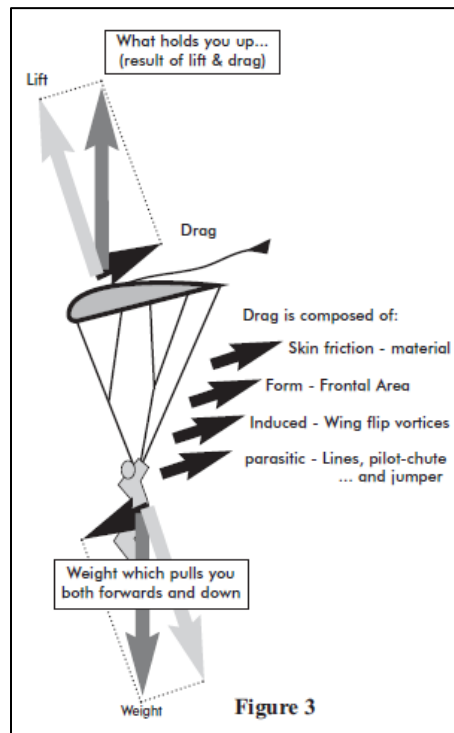


Figure 5. Free-body diagram of an air trooper. Source: Bayada et al. (2019).

2. Parachuting Path

All paratroopers follow a certain pathway from the opening height to the flaring height. Figure 6 shows the general route and altitude from the moment when the parachute opens until the landing area. By the 600 m (2,000 ft) point, the paratrooper should start thinking about the landing pattern. Appropriate training can allow a paratrooper to lose height, for example, by doing “S” turns. If the paratrooper is too low, he or she can maintain the altitude by applying some brakes (increasing the range by pushing down both toggles).

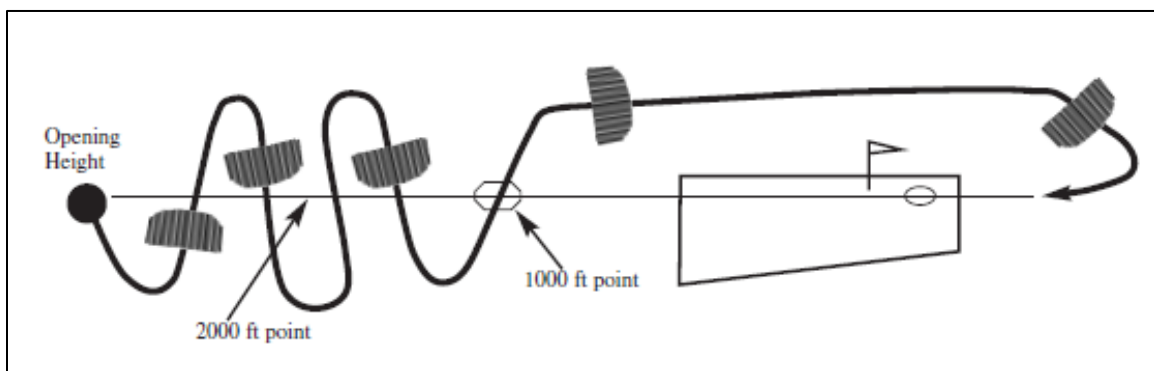


Figure 6. Landing approach path. Source: Bayada et al. (2019).

One important part of the parachute pathway is the 300 m (1,000 ft) point where the actual landing begins. If the individual is too high or too low, he or she can amend the plan by controlling the canopy, which will allow him to maintain or lose altitude and even change the landing pattern. Parachutes are designed so that in a perfect environment, the loss in height is the same as the distance traveled (Bayada et al., 2023). So, in an ideal flight without any wind at 300 m (1,000 ft), one is 300 m (1,000 ft) away from the parachute landing area (PLA). In other words, one can keep flying in a straight line. That is because, without wind, the ground speed (the sum of airspeed and wind speed) will be the same as airspeed since the wind speed is zero.

3. Landing Techniques

Many individuals require assistance determining the right moment to flare the canopy for a smooth landing. The ideal flare is executed seamlessly, with timing such that

the hands reach their lowest point at the exact moment when the feet touch the ground. However, without knowledge of the correct height at which to start the flare, the air-trooper becomes more dependent on luck rather than skillful judgment (Bayada et al., 2023).

One of the most used techniques for landing is the two-stage flare, in which the landing flare is broken down into two steps. In the initial phase, the toggles are moved from the full drive to the half brake position. The second stage is applying a full brake to “flare” for two to three seconds, about 1 meter parallel to the ground.

4. Static Line Parachute

The Skydive Perris webpage (2023) defines static line parachuting as “a form of skydiving that uses a static line (A cord attached to the airplane in one end and the other to the deployment bag), so when the individual jumps, the weight of this individual pulls the line and releases the parachute”.

Static line training (Figure 7) was originally developed for the military, which jumping in combat can be from relatively low altitudes. That type of jumping generally uses the MC-6 or T-11 parachute model, with the characteristic circular canopy (Perris, 2021).



Figure 7. Army paratroopers performing a static line jump. Source: Paolo Bovo (2022).

5. Accelerated Freefall (AFF)

Another type of skydive is the accelerated freefall (AFF), where the paratrooper begins with a free fall and then deploys the parachute after a certain period depending on whether it is a high altitude, low opening (HALO) or high altitude, high opening (HAHO) jump. The AFF jump typically uses a Ram air parachute, which provides greater maneuverability. The course that teaches how to perform this jump is the Military Jump School, primarily intended for Special Operations. Figure 8 depicts a common jump with this type of equipment. Some of the most common parachute models used for this type of jump are the MC-4 and RA-1.



Figure 8. Airborne personnel performing a Free Fall Jump for HALO training. Source: Hand, G. (2021).

Figure 9 shows the main components of this type of canopy (Ram air). The main elements for controlling the parachute are the toggles at both sides of the body and the two raisers: the front and rear raisers. Figure 10 shows the common harness components and elements of a Ram air parachute.

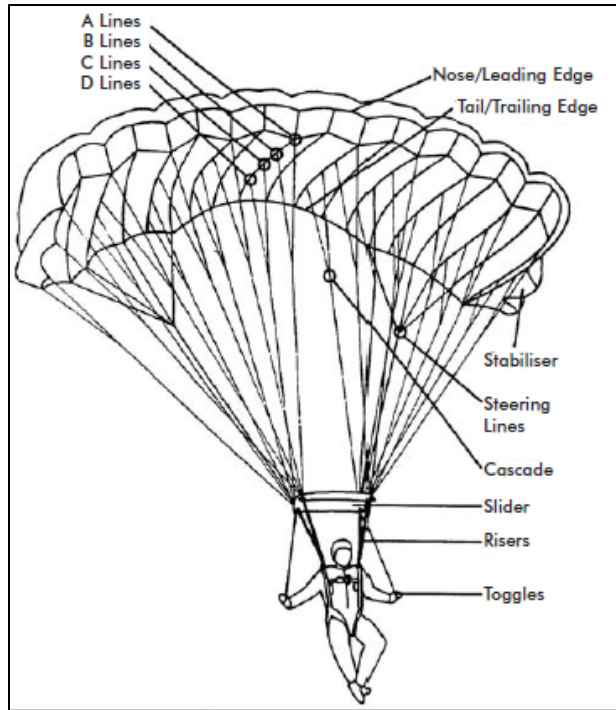


Figure 9. Components of a RAM air parachute. Source: Bayada et al. (2019).

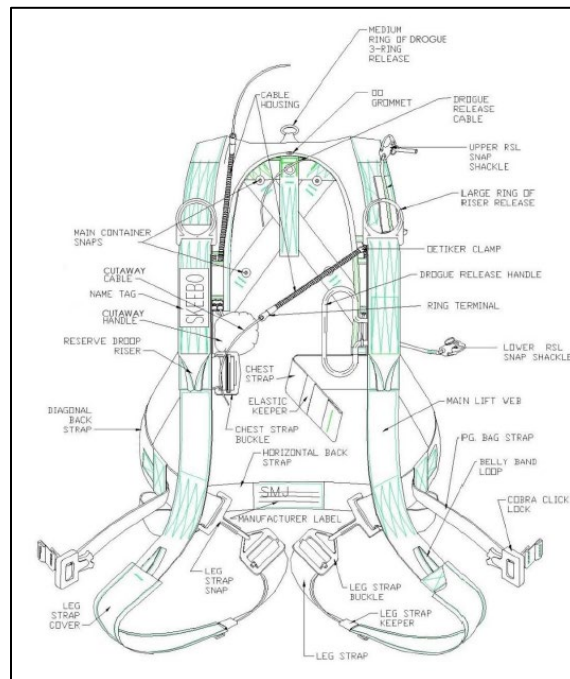


Figure 10. Parachute harness. Source: Bayada et al. (2019).

C. TRAINING PROCESS

A general approach to the training process that is currently followed at the Basic Airborne Course (BAC) in the U.S. Airborne School in Fort Benning, GA, is three weeks long and includes ground week, tower week, and jump week (Fort Benning, Basic Airborne Course (BAC), 2023).

1. Ground Week

The first week is intended to build individual airborne skills, and it mainly consists of mock door exercises, training on a 10 m high tower, and practicing with the lateral drift apparatus (LDA). It is understood that pulling the canopy toggles requires a force equivalent to 60% of the parachuter's body mass; the landing speed is 13 miles per hour, and the landing force is comparable to jumping from a height of 3 to 4 m (9 to 12 ft). Figure 11 illustrates the process and the sequence in which the different stages are performed.

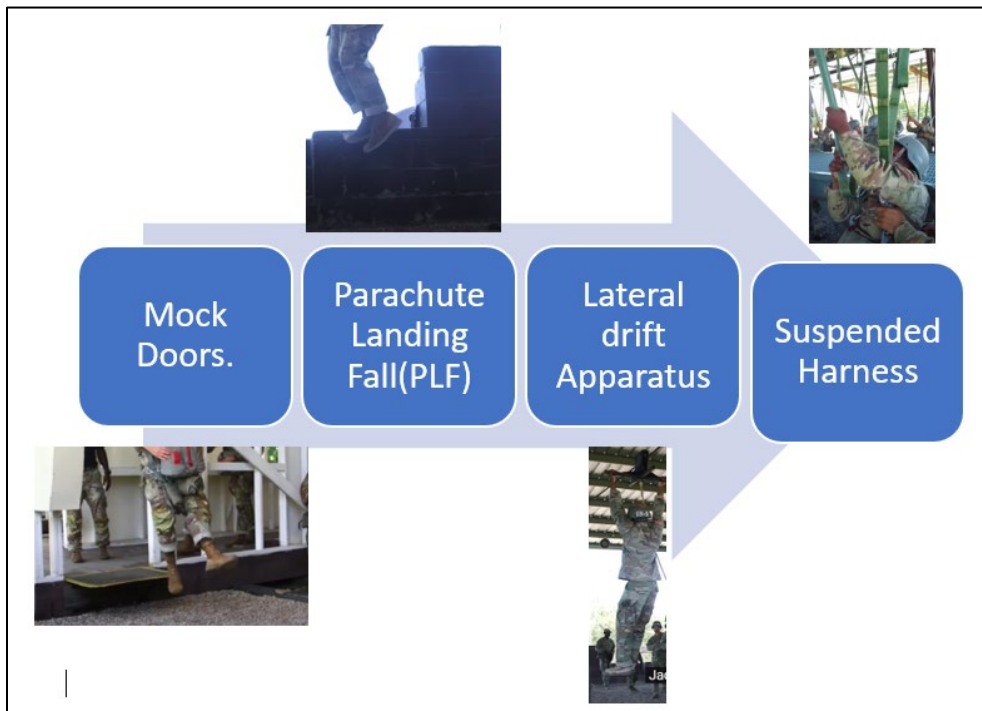


Figure 11. Parachuting training process. Fort Benning (2023).

2. Tower Week

According to the Fort Benning and basic airborne course webpages (2023), in this stage of training, participants undergo a process of skill refinement, focusing on individual abilities learned during the initial ground week. Additionally, training in team collaboration and mass evacuation concepts is integrated into the program. The training equipment used at this stage includes several tools such as 34 ft towers, a swing landing trainer (SLT), a mock door designed specifically for mass evacuation exercises, a suspended harness, and occasionally a 76 m (250 ft) tall free tower (Fort Benning, Basic Airborne Course (BAC), 2023).

Figure 12 illustrates a 10 m (34 ft) tower; that height is chosen because it is where humans typically start to feel fear. During this training stage, individuals count "1,000, 2,000," and so on, until they reach 6,000, which indicates that the canopy is fully deployed (it typically takes one second to say '1,000').



Figure 12. 34 ft tower. Source: Army.mil (2012).

Figure 13 shows the improved SLT, where the trainee does not look at the ground, and the instructor releases the trainees at random times, simulating when the trainee touches the ground. That can occur at any moment and so the trainee must be looking straight ahead. It is important to note that most injuries, such as broken bones and

contusions, occur on this apparatus. Therefore, this stage may have significant room for improvement with the help of a VR trainer that can replicate the approaching movement to the ground, as opposed to the improved SLT, which has been shown to cause many accidents.



Figure 13. Improved swing landing trainer. Source: Fort Benning (2023).

3. Jump Week

Finally, according to the Fort Benning webpage, during this week, trainees are required to complete a total of five effective jumps using the T-11 parachute from a C-130 or C-17 aircraft, with a jump altitude of 380 m (1,250 ft). (Fort Benning, BAC, 2023). Figure 14 shows the jump master getting ready for the jump.



Figure 14. Jump master preparing for a live jump. Source: Fort Benning (2023).

D. HEIGHT EVALUATION

The correct evaluation of height is a crucial aspect of the parachuting task as it helps the jumper determine the appropriate time to deploy the parachute, start the landing maneuvers, and perform the actual landing. Several methods can be used to evaluate height in parachuting, including using an altimeter, visual cues, and barometric pressure. The altimeter is a device that measures altitude or height above sea level; this device can be analog or digital, and some come with a built-in alarm. Experienced jumpers can estimate the height based on visual cues such as the size of objects on the ground, the shape of the landscape, and the speed of their descent. Finally, changes in barometric pressure can also be used to estimate altitude as the pressure decreases with increasing altitude. However, this method is not precise and requires new calibration depending on local weather conditions.

So, regardless of the method used, it is essential that jumpers have a reliable way of evaluating height during their jump to ensure a safe and successful completion of that task.

E. FINAL APPROACH AND FLARING STAGES

The specific domain of interest for this research study is the final approach and flaring stages of the jump. Therefore, the task analysis of these stages is crucial for correctly positioning and understanding the research questions.

Every jumper eventually enters the parachute landing pattern shown in Figure 15, consisting of the downwind, crosswind, and final approach phases. The final approach consists explicitly of a steady approach to the landing area and should be executed against the direction of the wind. In our experimental setup, the final approach will be different from the real-world scenario because there will be no wind, and the jumper's path will be a straight line.

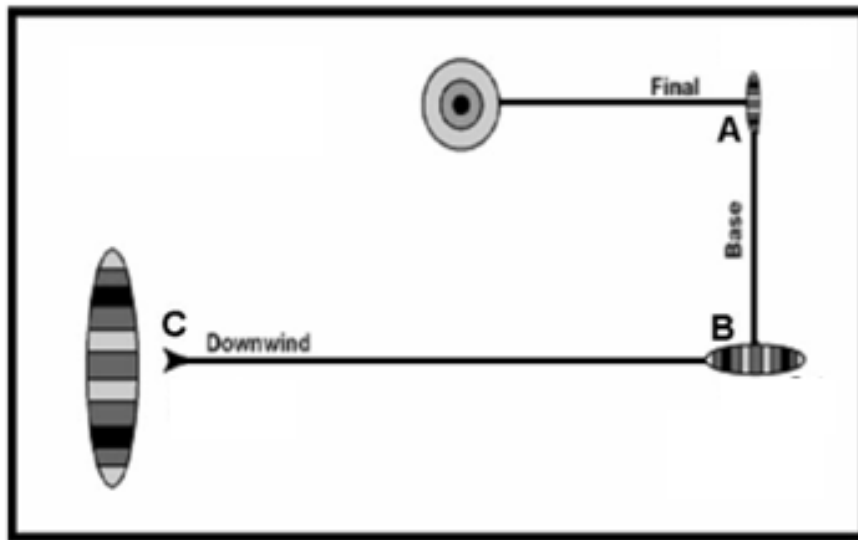


Figure 15. Parachute landing pattern

The flaring phase is when the jumper flies horizontally to the ground and very close to it with only forward speed (no downward speed). The flaring is also made by airplanes; it allows touching the ground softly because it reduces the downward speed in seconds

instead of hitting the ground directly. Figures 16 and 17 depict the flaring of the paratrooper.



Figure 16. Air trooper flaring. Source: iStock photos (2015).

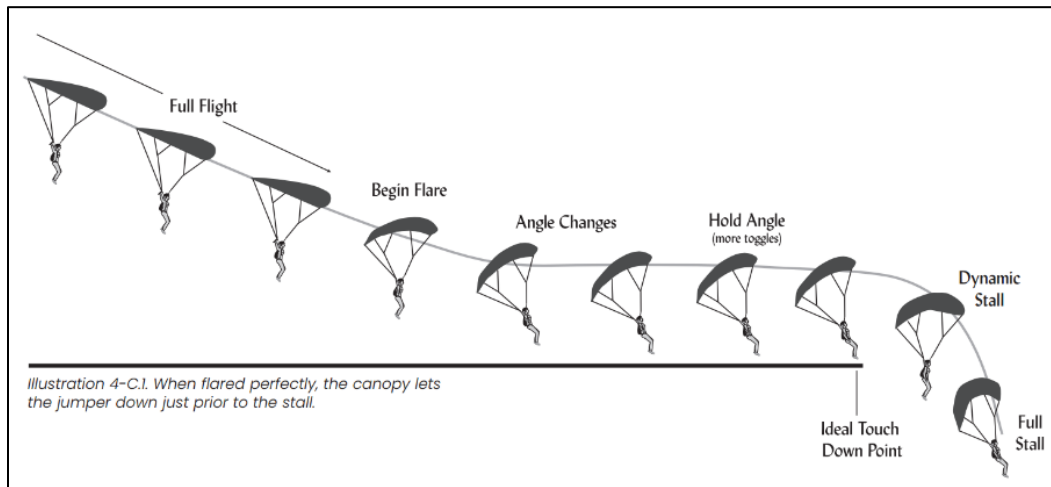


Figure 17. Flaring depicted. Source: Bayada et al. (2019).

F. SUMMARY OF PARACHUTING STAGES AND TECHNIQUES

The parachuting stages and important techniques associated with parachuting include the following:

Preparing for landing: This involves assessing the landing area, checking the wind direction, and determining the best approach. Paratroopers should aim to land in an open and clear area, avoiding obstacles such as trees, power lines, and buildings.

Controlling the parachute during descent: During the descent, the paratrooper must control the speed and direction of the parachute. This involves adjusting the steering toggles and controlling the brake lines, which allow the paratrooper to control the parachute's descent. Paratroopers must maintain a stable position, with their arms outstretched and their legs together, to maximize stability and control.

Executing a safe landing: The final stage of landing with a parachute involves executing a safe landing. Paratroopers should aim to land with their feet and knees together, absorbing the impact by rolling as they hit the ground. This helps to reduce the risk of injury and ensures a successful landing.

It is important to note that landing with a parachute requires significant physical fitness, coordination, and training. Paratroopers must be well-versed in the techniques and procedures involved in landing with a parachute and be familiar with the equipment they use. VR training is an effective tool that can help prepare the paratroopers for the challenges of landing with a parachute; the same training solution could become an essential part of the overall training process.

Completing the flare stage: This is a critical moment in the landing process for parachuting. The goal of the flare stage is to slow down the rate of descent and soften the landing impact, thus reducing the risk of injury. The following steps describe the process of executing a flare in parachuting:

Maintaining altitude awareness: Before beginning the flare, paratroopers must be aware of their altitude and the proximity to the ground. A typical flare is initiated at an altitude of around 15 to 12 ft.

Pulling down on the brake lines: As paratroopers reach the desired altitude, they pull down on the brake lines, which slows the descent rate of the parachute. The brake lines are attached to the rear risers, and pulling down on them causes the canopy to slow and descend more gently.

Arching the back: As paratroopers pull down on the brake lines, they also arch their back and bring their knees up towards their chest. This helps to distribute the impact of the landing over a larger area of the body, reducing the risk of injury.

Maintaining control: It is important to maintain control of the parachute throughout the flare process. Paratroopers must be aware of the wind direction and adjust the brake lines accordingly to maintain a stable descent.

Softening the landing: The goal of the flare is to soften the landing impact and reduce the risk of injury. Paratroopers should aim to land with their feet and knees together, absorbing the impact by rolling as they hit the ground.

It is important to note that the flare stage requires a great deal of coordination and skill, and a thorough understanding of the equipment and procedures involved. VR training might be an effective tool for preparing paratroopers for the challenges of the flare stage, helping them develop the skills and confidence they need to execute a safe landing.

G. MATHEMATICAL MODEL

Differential equations are very important to describe the world, and they are powerful mathematical tools invented to describe continuous rate of change over time or any other variable. Many natural phenomena can be modeled using differential equations (DE), like population growth and decay, chemical reactions, investment strategies, movement of physical particles, and even the outcome of combat.

The jumping of a person can be basically modeled with the following first order differential equation (ODE) (Phoebus & Reilly, 2004):

$$m \frac{dv}{dt} = -mg - kv, \quad v(0) = 0$$

The solution gives the position of the free fall body as a function of time from the moment the free fall starts until before the deployment of the parachute canopy for a time that is bigger than or equal to 0 and smaller than t_0 (the canopy deployment time).

$$y(t) = y_0 - \frac{mg}{k_1}t - \frac{m^2g}{k_1^2}\left(e^{-k_1\frac{t}{m}} - 1\right), 0 \leq t < t_0$$

After the canopy has been deployed, we use the first ODE:

$$m \frac{dv}{dt} = -mg - k_2v, \quad v(t_0) = \frac{mg}{k_1}(e^{-k_1t_0/m} - 1).$$

Once the former equation is solved, it yields the following equation which gives the velocity as a function of time; the time must be bigger than or equal to the time of canopy deployment.

$$v(t) = \frac{mg}{k_2}(e^{-k_2(t-t_0)/m} - 1) + \frac{mg}{k_1}(e^{-k_2(t-t_0)/m})(e^{-k_1t_0/m} - 1), \quad t \geq t_0.$$

Furthermore, we can obtain the position as a function of time with the following equation:

$$x(t) = x_0 + \frac{mg}{k} + \frac{m^2g}{k^2}\left(e^{-\frac{k}{m}t} - 1\right).$$

Figure 18 shows a graph of the relation between the speed and acceleration versus the time (Phoebus & Reilly, 2004).

It is important to note that in the system developed, the position of the paratrooper was delegated to the physical game engine and not simulated with the mathematical model to achieve a more realistic behavior of the elements when applying the toggle or interacting with other objects in the VE.

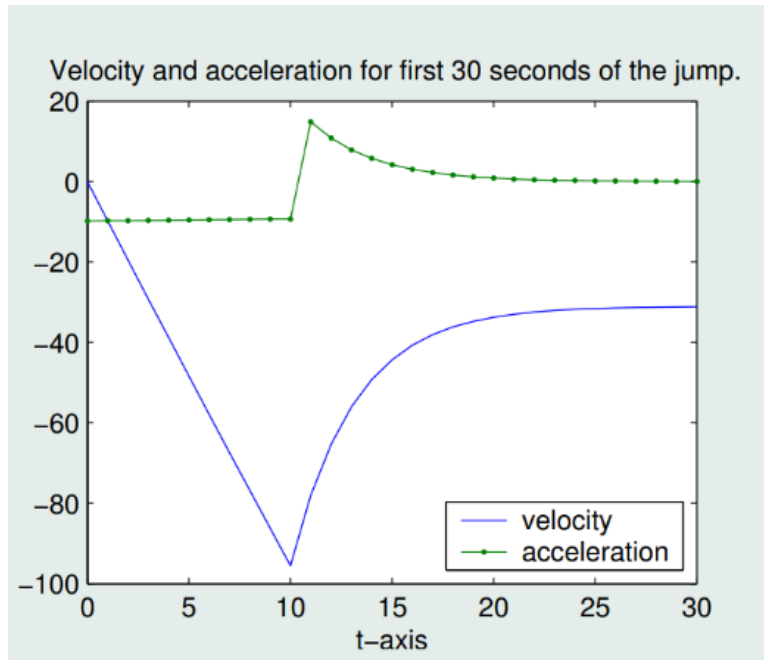


Figure 18. Graph of acceleration and speed versus time of an air trooper's jump. Source: Phoebus & Reilly (2004).

H. CHAPTER SUMMARY

This chapter detailed the process of landing with a parachute, including its steps: preparing for landing, controlling the parachute during descent, and executing a safe landing.

IV. DESIGN OF THE PROTOTYPE SYSTEM

A. INTRODUCTION

This chapter presents the system architecture and other aspects considered while designing the system prototype that supports the feasibility study. The results of the task analysis detailed in Chapter III are used to design the system and its user interface (UI). The overarching goal was to increase the realism of the user experience (UX). The starting point of the design process was the selection of two different types of terrains that mimic the environments in which the parachuting task is conducted. The central part of this feasibility study is the capacity to train personnel to correctly measure and judge the distance when approaching the terrain, thus increasing their potential for making the correct landing and avoiding injuries.

B. CONCEPTUAL AND LOGICAL DESIGN

Figure 19 shows the conceptual design for this system. In this design, we can see that the immersive environment is achieved through a series of different modules that increase the system's complexity and simultaneously provide more fidelity due to the addition of abstraction layers in a holistic way. Some of the essential elements of the prototype VR parachuter training system (VR-PTS) are the VR headset and the passive haptics.

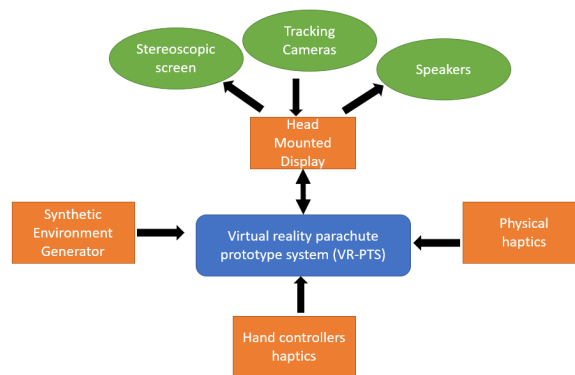


Figure 19. VR-PTS hardware conceptual design

Figure 20 shows the conceptual model for the software components that build the system. The VR-PTS is based on different technologies that together create the prototype system. First, at the lower level, the operating system supports the .NET framework that together with the Nvidia software will render the VR simulation to the application-level oculus link, the Imagen processing will then be transferred to the HMD, which will run a modified Android operating system, and on top of it, the Java virtual machine (JVM). Finally, on top of the JVM, the oculus link will communicate with its analogous part on the Imagen generation element.

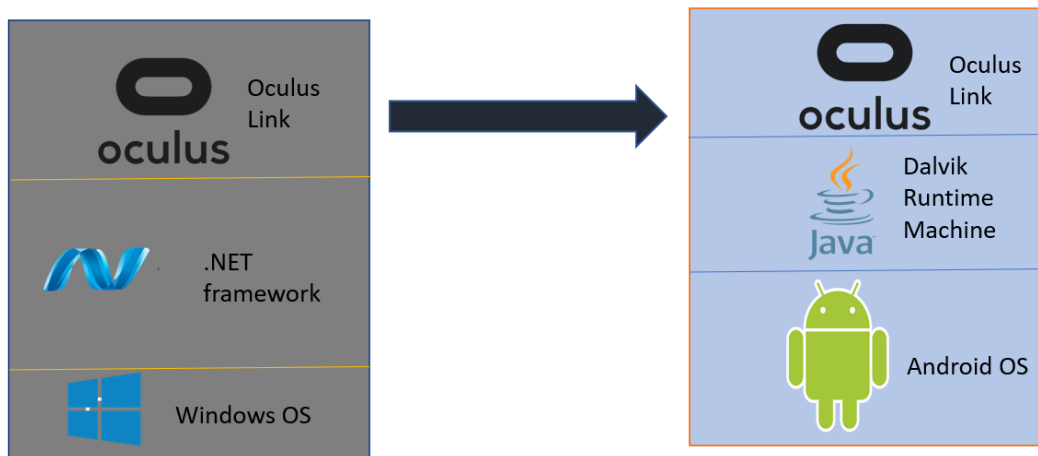


Figure 20. VR-PTS logic design

C. PHYSICAL SYSTEM ARCHITECTURE

The general architecture for the prototype is depicted in Figure 21; images are not shown in scale. This architecture shows how the image is rendered while utilizing a graphics processing unit (GPU) inside a dedicated PC; this approach allows rendering of the large, high-fidelity virtual environment and increases the overall image quality. Since the processing power and graphics card of the HMD are lower than the capabilities of similar hardware components inside the PC, the headset is used only to display the resulting images and sounds while using the camera and controller's data as inputs for the game engine. Communication between the Meta Quest 2 and the PC is achieved through the Meta application known as the Oculus Link. We decided to use three display monitors with the

PC; this way, the experiment operator could observe what the jumper was seeing and doing in the virtual environment while performing the task.

The hand tracking is supported by the Oculus Integration v39 application, released in April 2022 and available from the Unity Asset Store. The main purpose of the Meta Quest 2 controllers is to bring user input (signals) to the system.

As Figure 21 shows, the central part of the physical setup consists of a metal structure—a stand—that holds the seat and the harness. Both elements act as passive haptic devices—the physical props that produce needed tactile and haptic responses for the user. It is important to note that there is no electronic link between those elements and the rest of the system (VR-PTS application); they are specifically designed to hold the user’s body in a seated position. The main reason passive haptics are used is for the user to feel the harness and the seat, allowing for slight body rotation in the air (seat), thus increasing a sense of the overall realism of the experience. The parachute toggles are simulated by attaching the controllers to two long spring cords that are connected to the main stand.

Furthermore, the HMD is attached via a 3.0 USB cable type C to the PC via Oculus link; the headset can then provide wind sound for a more immersive experience. The headset also provides the output for the stereoscopic image rendered on the PC.

Finally, the setup includes the research operator station (ROS) which consists of three monitors connected to the PC graphics card. These monitors provide an image, and at the same time, they also serve as the operator control area to manipulate the system and keep a record of the data that is collected in the experiment.

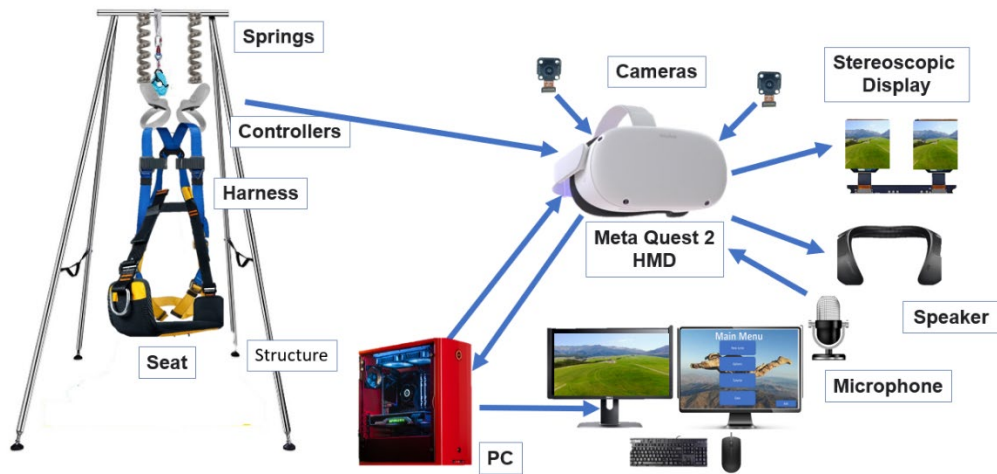


Figure 21. Physical system architecture

D. TERRAIN DESIGN

Since the terrain element plays an important role in this research effort, special attention is given to the selection and design of its topography; the goal was to achieve high fidelity of terrain definition. Figure 22 shows an example of a high-resolution image that was rendered using the High-Definition Render Pipeline (HDRP) and the Unity Game Engine.



Figure 22. High-definition Render Pipeline terrain in Unity. Source: Unity Store (2023).

Landscapes can be integrated into the application using the built-in terrain tools of the Unity simulation engine. A variety of terrains can be made in the editor; one can change the height or style of the landscape and include a diverse set of additional objects like trees, rocks, or grass.

1. Orography

Orography is the difference in elevation of the land of the terrain. There are two types of terrain, first order and second order terrains. First order terrains consist of plains, valleys, plateaus, hills, and mountains; they are considered when designing the VR environment.

Conversely, second order terrain consists of terrain cracks, small elevations, and unique elements such as small human-made water channels. These elements are not contemplated in the VR ecosystem needed for this research.

2. Meteorological Elements

These elements are related to the state of the atmosphere at each time, and they are represented by the temperature, atmospheric pressure, wind speed, direction, fog, and rain.

The terrain and virtual environments used in this research do not use meteorological elements.

3. Hydrography

Hydrography refers to everything related to water masses, such as rivers, lakes, and streams. From these elements, only the lake is simulated in the VR environment, but it has a secondary role in the experiment (that is, to augment the level of realism in the environment).

4. Vegetation

Different components can be considered in this category, including the type of vegetation (trees, bushes, flowers, grass), density, location, or if it is wild vegetation or farmed. These elements are considered when designing the VR terrain because they influence the height perception of the airborne personnel during the landing.

5. Artificial Elements

Artificial elements are made by humans, such as towns and installations; these elements are not used in our research.

6. Astronomical Elements

The position of the sun, such as sunset, sunrise, and twilight, i.e., the hour of the day and the light, plays an important factor when dealing with human activities. They play a significant role in training, so these elements are included to some extent; we simulate a particular time of the day and the effects the sun makes when it interacts with the objects in the environment (shadows).

E. OPERATOR INTERFACE DESIGN

Figure 23 is a diagram showing the general screen flow, illustrating samples of the user interface for the system operator who executes the experiment. Each screen is introduced with its function and design in the following sections.

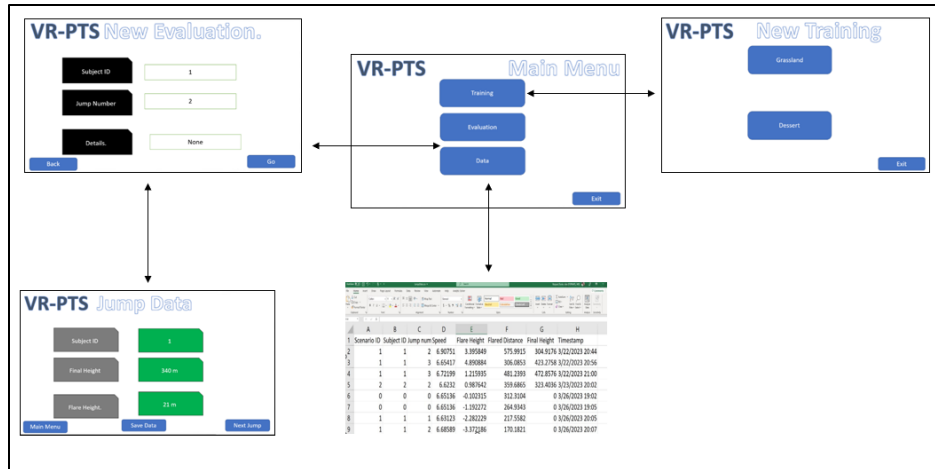


Figure 23. Screen flow diagram

1. Main Menu

The main menu (Figure 24) is the starting point where the research operation station, or ROS, allows the operator to navigate among different screens during the experiment.

The selection of ‘Training’ or ‘Evaluation’ simulates jumps with different speeds, positions, and objectives for every jumper. The main difference between the Training and the Evaluation mode is that in Training mode, the user sees textual information that simulates an altimeter, identifying the exact vertical height from the user’s eyes to the ground.



Figure 24. Main menu screen.

2. Terrain Selection Screen

The Training screen allows the operator to choose between different synthetic environments. Figure 25 depicts the Training screen with a choice of grassland and desert environments.



Figure 25. New Training screen

3. Evaluation Screen

When the training phase is completed, the evaluation phase can be accessed through the Evaluation screen (Figure 26). This screen allows the operator to set up the required parameters and save the information about the subject and the jump session. A subject ID rather than an individual's name or other personally identifiable information is used to protect anonymity and prevent unauthorized disclosure of personal information. The jump number is needed to create the details for a new jump in the evaluation scenario with different values such as height, destination objective, and initial position and rotation of the canopy.

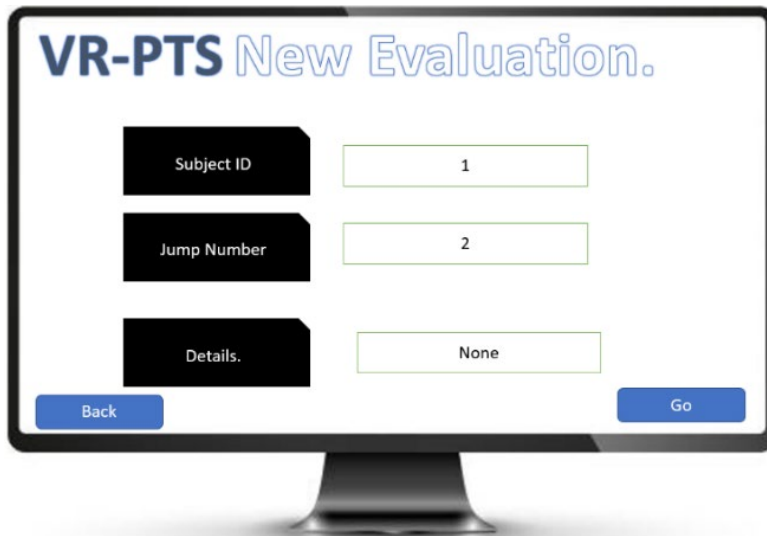


Figure 26. New Evaluation data screen

4. Jump Data Screen

Figure 27 shows the screen with the jump data information to the operator about the user's performance. It presents two important pieces of information: the final height and the flare height the subject indicated to the system during the virtual landing. From here, it is possible to navigate to the main menu, save the data, or go to the next jump.

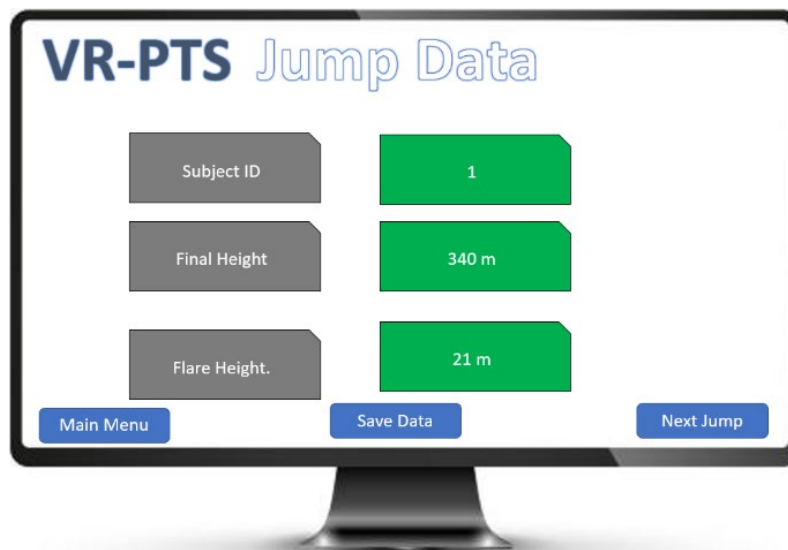


Figure 27. Jump Data output screen

5. Data Collection

The final data set collected for each user (subject) has the complete information from all previous jumps in a comma-separated values file (CSV); this way, the operator can perform different types of analysis. The data recorded for the experiment consist of the scenario ID, subject ID, jump number, speed when hitting the ground, flare height as indicated by the subject, final height as indicated by the subject, the distance from the landing point to the PLA, and the straight distance from the flare and final points that were chosen to the PLA. Finally, the timestamp of the record creation is saved for debugging purposes. Figure 28 shows the information collected.

	A	B	C	D	E	F	G	H	I
1	Scenario ID	Subject ID	Jump num	Speed	Flare Height	Flared Distance	Final Height	Timestamp	
2	1	1	2	6.90751	3.395849	575.9915	304.9176	3/22/2023 20:44	
3	1	1	3	6.65417	4.890884	306.0853	423.2758	3/22/2023 20:56	
4	1	1	3	6.72199	1.215935	481.2393	472.8576	3/22/2023 21:00	
5	2	2	2	6.6232	0.987642	359.6865	323.4036	3/23/2023 20:02	
6	0	0	0	6.65136	-0.102315	312.3104	0	3/26/2023 19:02	
7	0	0	0	6.65136	-1.192272	264.9343	0	3/26/2023 19:05	
8	1	1	1	6.63123	-2.282229	217.5582	0	3/26/2023 20:05	
9	1	1	2	6.68589	-3.372186	170.1821	0	3/26/2023 20:07	

Figure 28. Jumps data log information

F. CHAPTER SUMMARY

In this chapter, we reviewed the details of the VR-PTS design, including its logical, physical, and conceptual diagrams, the design of the terrains used in the study, and the user interface for the operator.

V. DEVELOPMENT

A. INTRODUCTION

The development stage is an integral part of the work on any system prototype, including the VR-PTS. During this stage, the design ideas and decisions presented in the previous chapter are brought to reality using different technologies, tools, solutions, and approaches. This chapter discusses the key phases of developing the VR-PTS prototype: the VR system's development and the physical setup construction.

B. VR SYSTEM PROTOTYPING

Developing a VR system from scratch is a complex task, requiring a diverse set of tools to carry it out effectively. One of the most significant advantages of developing COTS prototypes is the availability of mature game engines, which can help develop applications relatively quickly. The development environment they provide includes software development toolkits (SDK) and application programming interfaces (API) to enable deployment on different platforms relatively easily and quickly.

Unity, Unreal, and CryEngine are among the most frequently used game engines in the gaming industry. To provide the best support to developers, their IDE needs to be flexible and have well-developed documentation, including a wealth of tutorials that address developers' learning curve. Figure 29 gives an example of a modern IDE game engine.

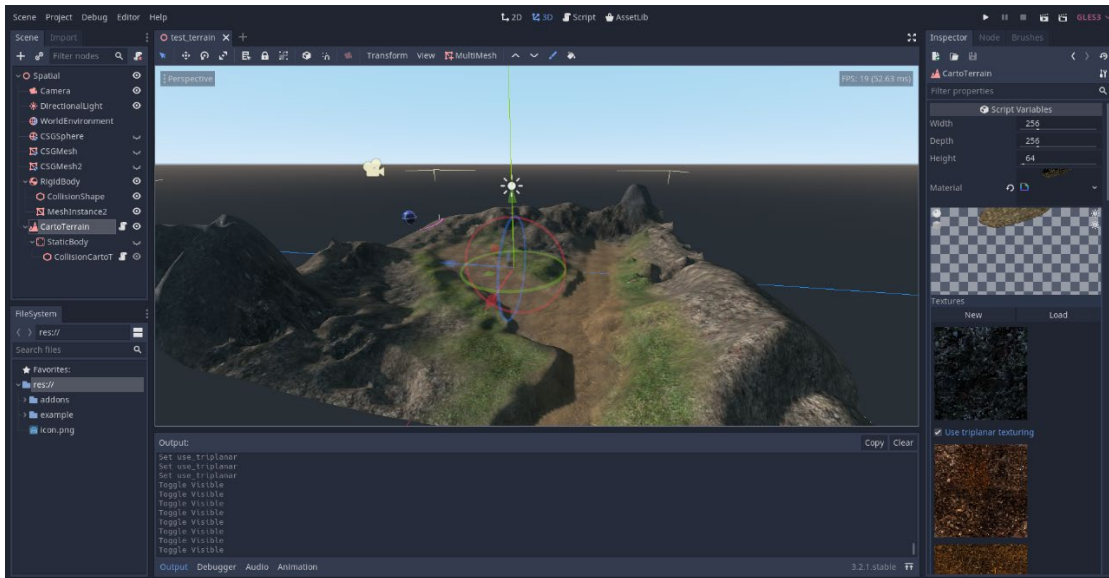


Figure 29. Example of a modern game engine IDE. Source: Unity Store (2023).

1. Unity High-Definition Render Pipeline (HDRP)

Unity is a cross-platform game engine used to develop 2D and 3D video games. It provides an integrated development environment that includes design, scripting, animation, and asset management tools. Unity supports multiple operating systems and platforms, such as Windows, macOS, Android, iOS, and Linux, allowing developers to create games and other 3D applications that can run on multiple devices. Additionally, Unity offers other features, such as physics simulation, networking, and audio mixing, making it an all-in-one solution for systems prototyping. Its relative ease of use, flexibility, and strong user community has made it one of the most popular game engines in the industry. However, it is generally accepted in the developers' community that the quality of the synthetic environment could be better and that the resource optimization is lower than with other, more sophisticated game engines with less flexibility.

Unity version 2021.3.17f1 long-time support (LTS) was used to develop the VR-PTS system prototype; Table 1 specifies the tools and the versions used in that process.

Table 1. Tools used for the development of the VR-PTS system

Tool	Version
Unity Hub	3.4.1
Unity Game Engine	2021.3.17f1 LTS
Developer Tools	Microsoft Visual Studio Community 2019
HDRP	13.1.18
Oculus Link	50
Oculus Integration	37.0

The Unity HDRP is well-suited for creating immersive experiences in the Oculus (now Meta) family of VR headsets. With HDRP, it is possible to take advantage of its lighting and graphics capabilities to create more realistic VR environments. The pipeline supports real-time reflections, realistic shadows, and physically based materials, all of which can help to increase the level of realism and indirectly heighten a sense of presence in the user’s overall VR experience. By using HDRP with Oculus VR, one can create fully immersive and engaging experiences. The version of HDRP used for this work was 13.1.8. (Figure 30).

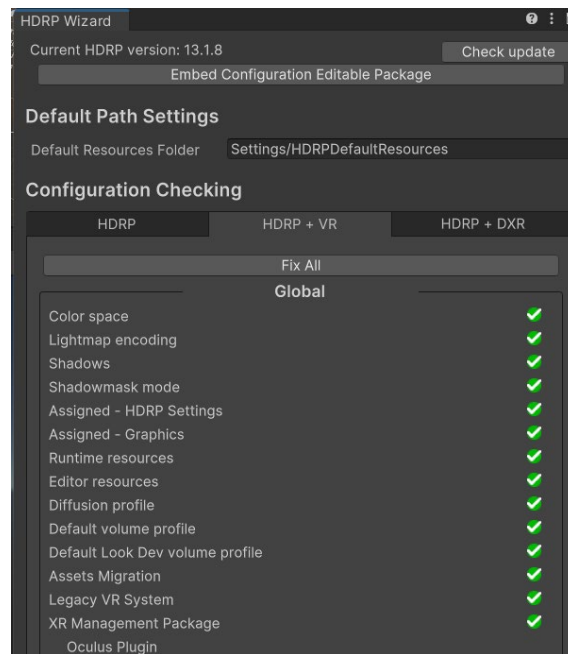


Figure 30. HDRP plus VR for Unity checklist

2. Oculus XR Plugin

The Oculus XR Plugin is an SDK that enables developers to build and run immersive cross-reality experiences on the Meta Oculus platform. This plugin supports virtual reality and augmented reality display devices, allowing developers to create applications that work seamlessly across different XR display solutions. The Oculus XR Plugin includes a range of tools, features, and services that help developers build high-quality XR experiences, such as hand and controller tracking, graphics rendering, and audio spatialization. The version used in this study was 3.2.2, released in November 2022.

3. Oculus Link

Oculus Link is a software application created by Meta to connect the Meta Quest headset to a PC through a Wi-Fi interface (called Air Link) or through a USB type C cable with a 3.0 USB port. That application allows one to use a PC—a hardware system with more processing power than the headset—as a system that will render synthetic information and prepare images and use the headset only to display the same images. Since the wired option gives more bandwidth and stability than the wireless connection, and the user does not need to move physically through the space, the wired option is preferred for VR-PTS. The Oculus Link capability is achieved by downloading the Oculus application, installing it on the PC, opening it, and adding the device (Figure 31). In the headset, one needs to find Oculus Link in the device settings and launch the Oculus Link dialog. Optionally, the Meta Quest developer hub can be installed to debug and increase the game’s performance. For the present work, the version used is Oculus App Version 50.

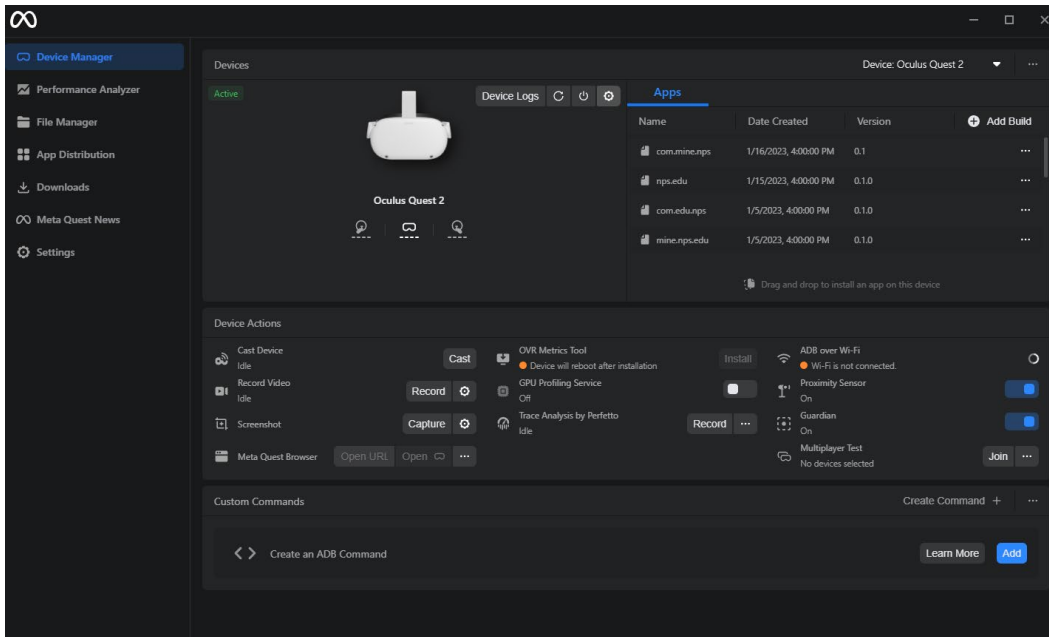


Figure 31. Oculus Quest PC application

4. Oculus Integration Package

According to the Oculus development webpage (2023), the integration package “brings advanced rendering, social, platform, audio, and Avatar development support for Oculus VR devices and some Open VR-supported devices” (Unity Asset Store, 2023). The version used for this project is Oculus integration package 37.0, released on January 25, 2022 (Figure 32).

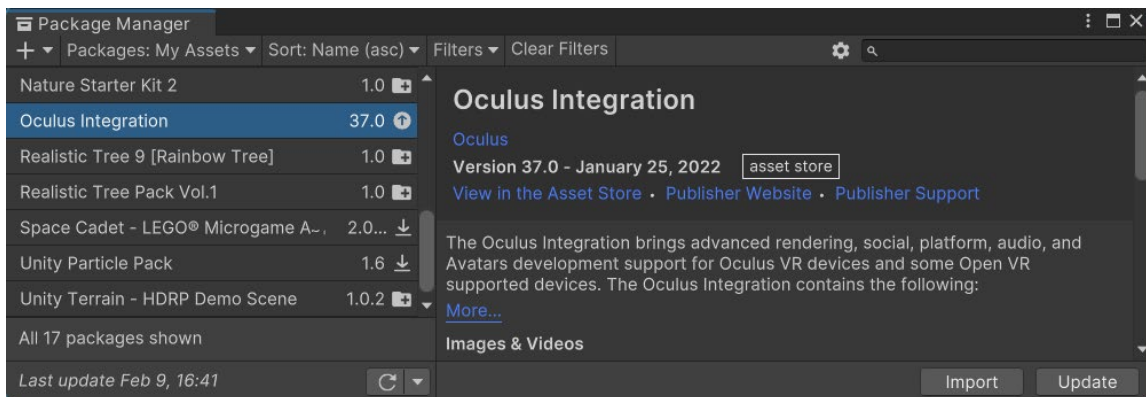


Figure 32. Oculus integration

The Oculus Quest 2 is a standalone VR headset with integrated support for the Unity game engine. This integration allows developers to easily create and publish applications for the Oculus Quest platform using Unity's development tools and features. Unity provides a suite of tools for VR development, including a VR Editor, and a VR rendering pipeline, which simplify the process of creating VR experiences. Additionally, Unity's support for the Oculus Mobile SDK enables developers to access the full range of features available on the Oculus Quest, such as hand tracking, room-scale VR, and the ability to run applications without a PC. With the combination of the Unity engine and the Oculus Quest 2, developers have a powerful toolset for creating high-quality VR games and applications.

The relation between the Oculus integration and XR plugin can be seen in Figure 33.

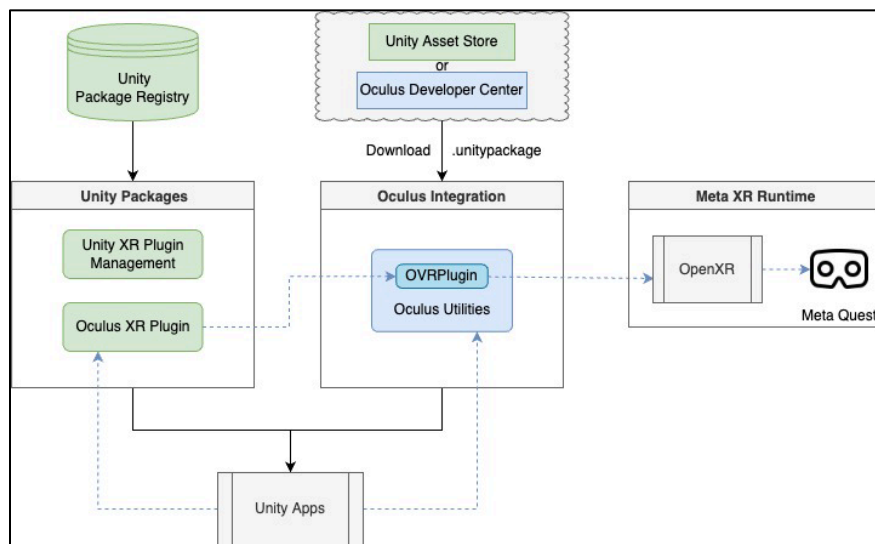


Figure 33. Oculus XR and Oculus Integration in Unity. Unity Store (2023).

5. Microsoft Visual Studio

Microsoft Visual Studio 2019 IDE is the default application for scripting in the Unity game engine; even though there are more tools available, both free and commercial, Visual Studio has all the capabilities needed for this study. Productivity can be increased

using this tool thanks to the built-in capabilities of the IDE, such as IntelliSense, code auto-completion, and suggestions for fixing errors. Also, powerful and user-friendly debugging tools can considerably decrease the time needed to deploy an application to production.

6. Synthetic Scenes Development

The Unity IDE element that works as the principal structure and backbone for all the objects and the interactions between them is the “scene.” Different scenes and user interfaces were developed to support the functionality required for the study: a grassland virtual environment, desert virtual environment, and a set of user interfaces for the operator (the experimenter).

a. Grassland Environment

The grassland environment was designed to represent a grassland valley; it was developed using the Unity HDRP Terrain Demo Scene as the base. The scene contains a square terrain with a side length of 5,000 m (an area of 25 square km). The maximum altitude of the terrain is 800 meters in the surrounding hills. A skybox surrounds the terrain tiles, but that object is not a part of the terrain. The scene orography is a valley surrounded by ice-covered mountains. Inside the valley are second-order elevation elements and a lake. The vegetation consists of different types of flowers, grasses, bushes, and trees, represented with a relatively high level of realism (Figure 34).

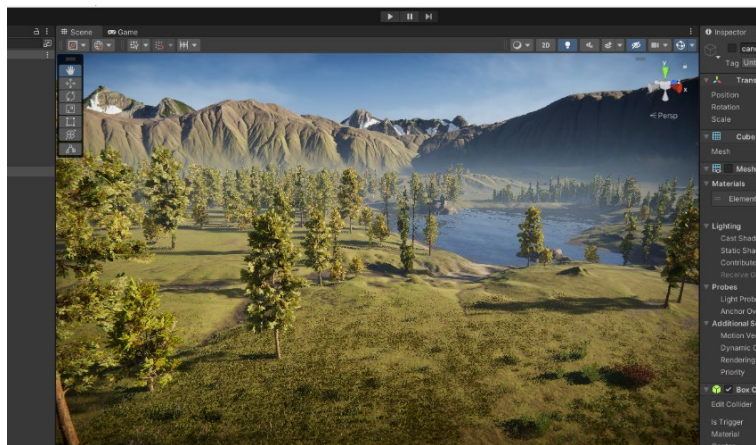


Figure 34. Grassland evaluation scene

The scene also contains a wind object to add movement to the vegetation; the influence of the wind was excluded from the canopy mechanics. The wind element is part of the standard Unity toolkit and can be used without modification.

Parachute object and the avatar: The parachute game object is an essential element added to the scene; it contains the parachute object, the jumper avatar, and the mechanics of the Oculus Virtual Reality Camera Rig that comes with the Oculus Integration software. The Oculus Rig enables a stereoscopic view from the virtual world and the API required to control the Oculus controllers through the controller's grab interactors (Figure 35).

Sound effects: To increase the level of realism, an audio source element that resembles the sound of the wind that the parachuter would hear while falling was added to the grassland scene. The Integrated Oculus Quest speakers reproduced the sound effects.



Figure 35. Canopy game object

Scripts: A set of scripts was developed to enable the functionality needed in the VR-PTS (Figure 36). These scripts were added using the object-oriented programming (OOP) paradigm using classes written in C# programming language. They included the following set:

- The Canopy Positioner script allows a selection of different starting positions for the canopy depending on the jump number.
- The Maneuvering Control script allows the subject to steer the parachute with the controllers while in the air. It works by measuring the relative height difference between the two Oculus controllers and applying a vector force in the corresponding canopy position where the controller has been pulled the furthest distance, rotating the parachute in the same direction as the pulled controller. This script was fully developed; however, it was excluded from the study to simplify the user interaction and allow the user to focus only on the evaluation of the heights.
- The Player Collision script senses when the parachute hits the ground and triggers the logic that follows that event, such as the parachute rotation on the ground.
- The Flight Recorder script measures the distance from the parachute to the ground using a ray traced from the parachute to the ground.
- The Height Chooser script allows the participant to choose both the final approach and the flare height by pressing any of the controllers' buttons.

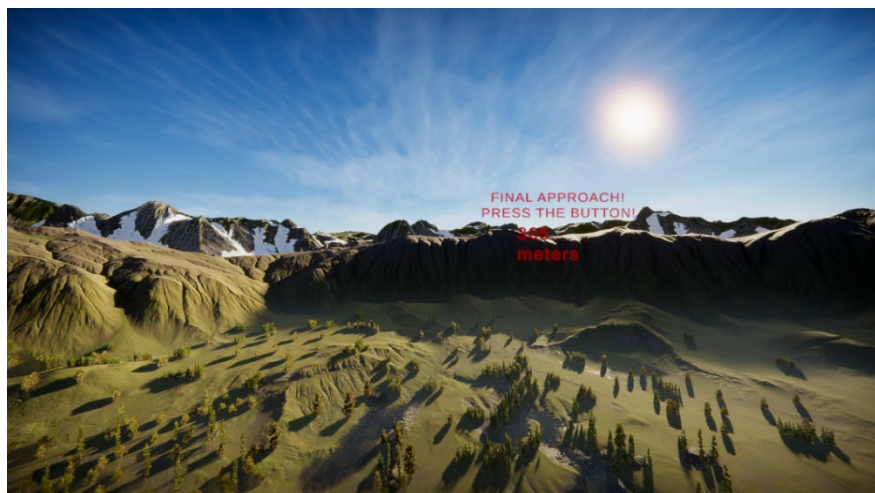


Figure 36. Grassland training environment showing the scripts functionality

b. Desert Environment

The second environment that was used for the evaluation of heights in the user study was a desert environment; it was created using the HDRP technology.

The desert terrain consists of an irregular circle with a 2,500 m diameter and 25 square tiles with a side length of 500 m. The maximum height of the terrain is 600 m. A skybox of mountains surrounds the terrain, and the environment is lit with a fainter light (when compared to the grassland environment).

The soil is covered with red dunes and boulders; the dunes' height varies, and the vegetation is almost nonexistent (Figure 37). There are no hydrological elements such as rivers or lakes, which makes this environment simpler but, at the same time, more complicated for the subjects to determine the height (altitude).

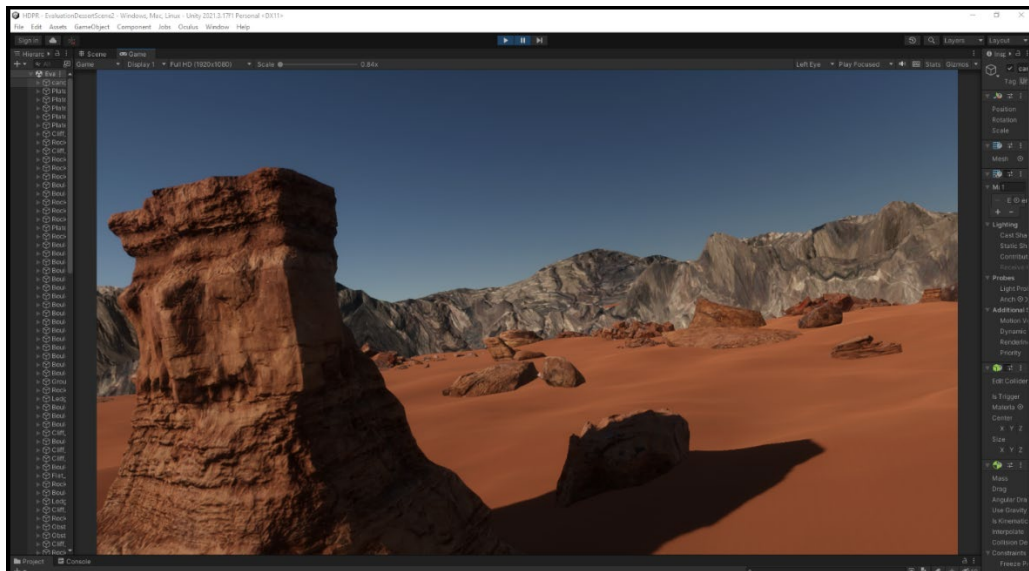


Figure 37. Desert terrain evaluation scene in IDE

The canopy, avatar, and sound from the grassland are included in the desert environment as well. Most of the C# scripts are also shared by both environments except for the “Height Chooser” script, which had to be adjusted to the dimensions of the desert terrain.

The “Game State Controller” class is used as a runtime database to share data between different objects and scenes; it saves all the data needed as identifiers in the study, such as the jump number, chosen final height, chosen flare height, scenario, and flying height. Figure 38 shows the desert scene in the development phase.

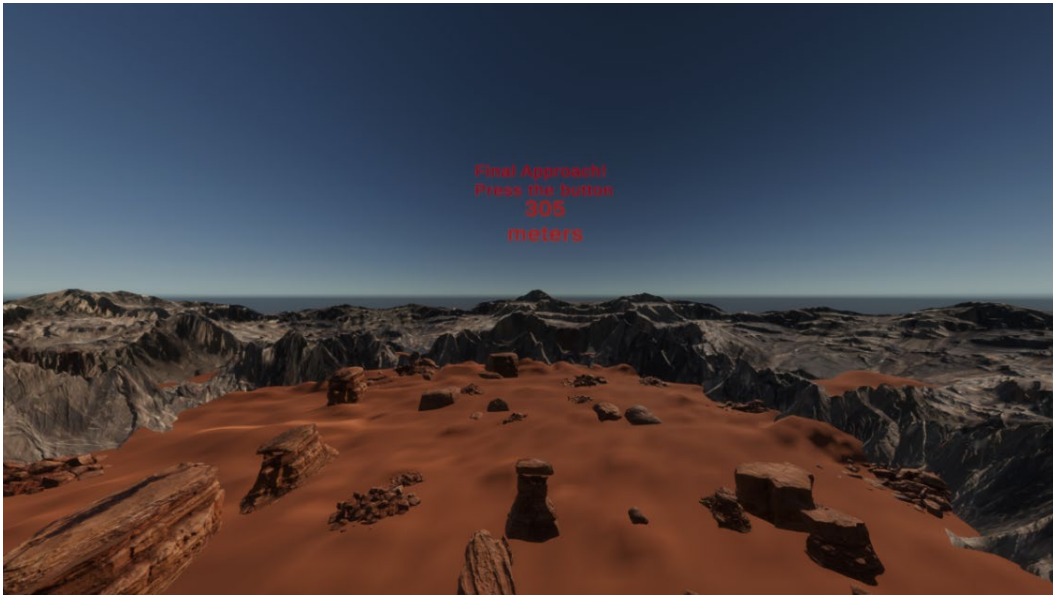


Figure 38. Desert training scene at final approach in development

c. Menu and Navigation

The menu and navigation scenes are developed to provide a user-friendly workflow for the operator to conduct the experiment, and to save and retrieve the data captured during each virtual session. The main menu was developed as an independent scene that works as the starting point for the system prototype application (Figure 39). The Main Menu script controls all the logic and allows one to navigate to different scenarios.

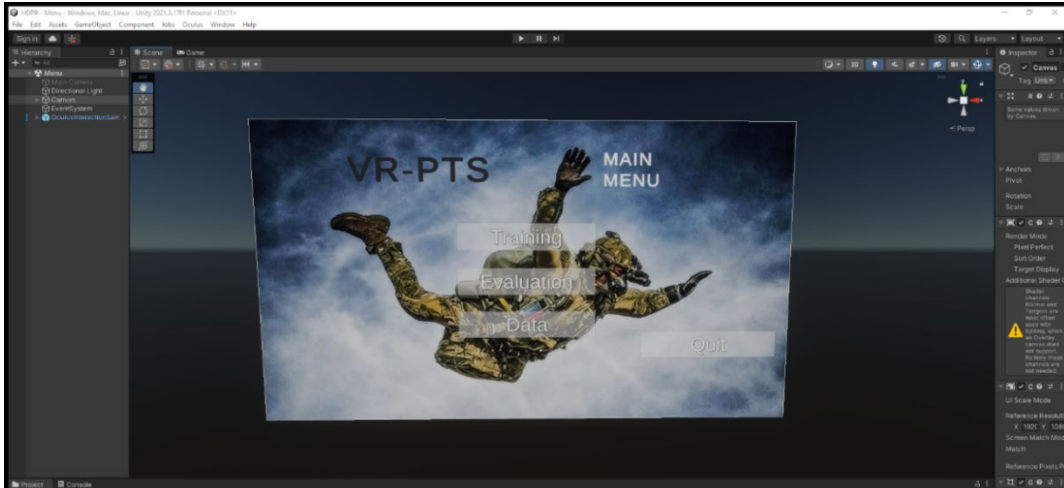


Figure 39. Main Menu scene

Another vital functionality developed to store persistent data (not only the runtime memory saved at the random-access memory) is the save data flight scene. With the functionality provided by the Jump Data Controller script, it is possible to save the Flight Data set, such as the timestamp, final height, flare height, and landing speed, in a spreadsheet by pressing a button offered via the user interface (Figure 40). The same data set can be retrieved in the main menu or accessed directly through Windows File Explorer and opened with Microsoft Excel or any other compatible application.

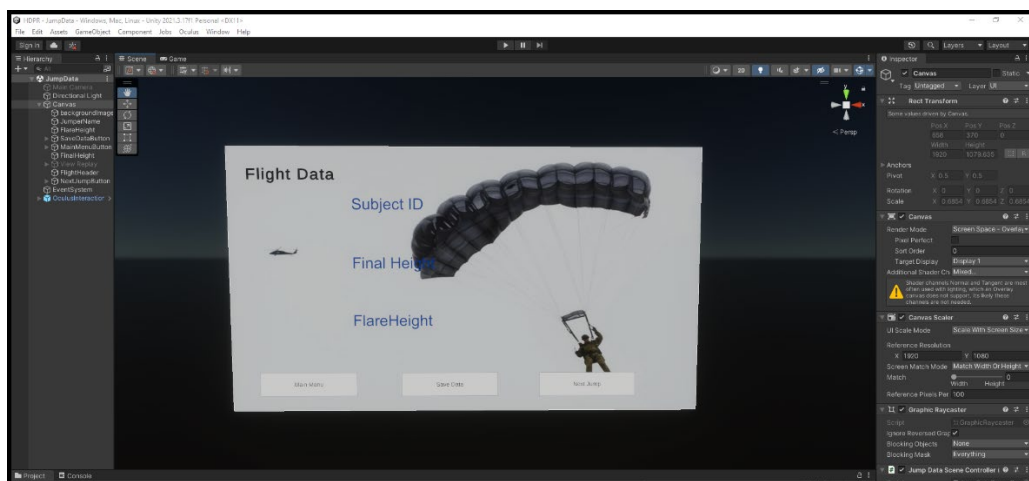


Figure 40. Scene interface for saving the experimental data

C. COTS HARDWARE SOLUTIONS

Choosing the optimal elements is of critical importance in developing an effective and robust system that can be acquired and used by many potential users.

1. Head Mounted Displays and Meta Quest 2

HMDs have become an increasingly popular visual display devices for experiencing virtual reality. The displays create stereoscopic images that allow users to experience the illusion of 3D; the user can look around the virtual environment simply by moving his or her head. One of the primary benefits of HMDs for VR is the immersion level they can provide, in which users are surrounded by synthetic images, and the visual information from the real world is shut off. We call those display solutions *fully immersive*.

A wide range of VR applications are specifically developed for HMDs. Although commonly used for gaming, they are increasingly used in the training and education domains, providing a safe and controlled environment for learning complex skills or practicing dangerous tasks.

HMDs are a powerful tool for experiencing virtual reality. They offer a similarly high level of immersion and can be used in a wide range of applications, from gaming to training and education. While there are some challenges to overcome, such as the issue of nausea, the potential benefits of HMDs in VR are enormous. HMDs will undoubtedly become even more prevalent in virtual reality as technology improves.

The Meta Quest 2 (previously known as the Oculus Quest 2), manufactured by Meta is an updated version of the original Oculus Quest, featuring a similar design but with enhancements such as reduced weight, higher refresh rate, improved per-eye resolution, and updated Oculus controllers (“Quest 2,” 2023). Table 2 lists the technical specifications of the Meta Quest 2.

Table 2. Oculus HMD technical specifications.

Weight	503 grams
Processor	Qualcomm Snapdragon XR2
RAM Memory	6 GB of LPDDR4X
Display	Single fast LCD panel
Display Resolution	1832 x 1920 per eye
Refresh Rate	120 Hertz.
Operating System	Android based
Controllers	Oculus Touch with accelerometer and gyroscope
Storage	128 Gigabytes
Graphics	Adreno 650
Input	6 Degree of Freedom (4 built-in cameras and 2 controllers)

Figure 41 depicts the Meta Quest 2 (previously known as the Oculus Quest 2).

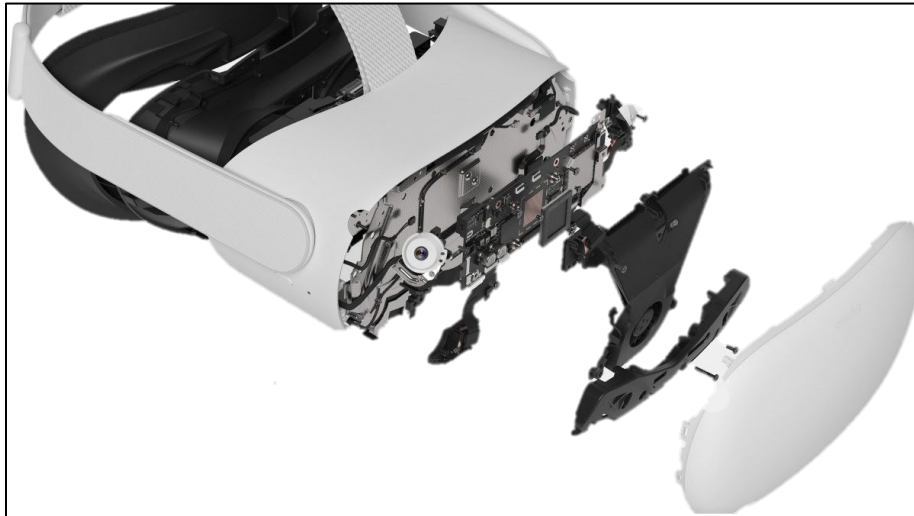


Figure 41. Meta Quest 2 disassembled. Source: Meta Inc. (2023).

Figure 42 shows one of the Meta Quest 2 controllers that allow users to interact with the synthetic environment.



Figure 42. Meta Quest controller. Source: Meta Inc. (2023).

2. PC Platform

Table 3 provides details about the technical specifications of the PC platform used for the development of the VR-PTS prototype.

Table 3. PC technical specifications

PC Model	origin
Processor	Intel Core i9 @ 3.3 Ghz
RAM	64 GB
Graphic Card	NVIDIA GeForce GTX 3080 ti (8GB)
Operating System	Windows 10 Home. Build 19045.2604

3. Stand and Passive Haptics Elements

The following equipment was acquired to set up the physical stand: A 9.6 ft tall metal frame structure that supports the seat, harness, and controllers. The stand can hold up to 551 lbs (250 kg) and has steel tubes that have a diameter of 1.8 in (Figure 43).

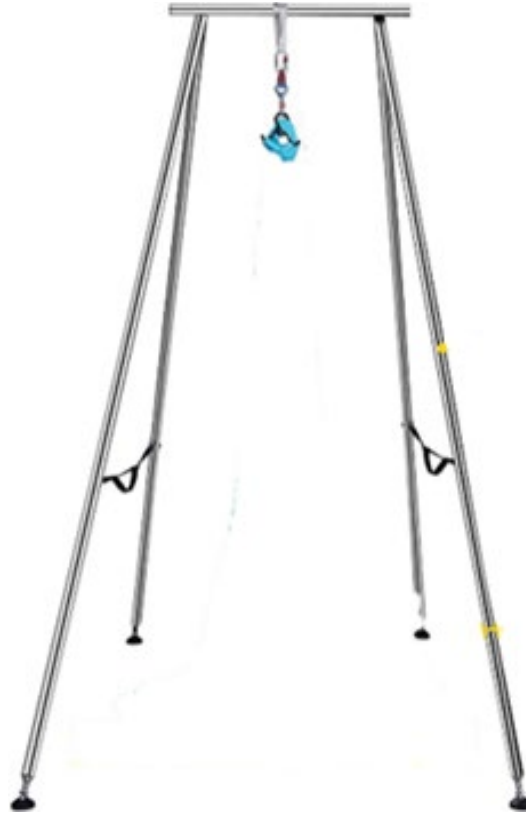


Figure 43. Metal structure for the setup

Another important element was the Werner full-body harness model and the seat; the seat helped keep the subject comfortable over an extended time. Figure 44 shows the harness, which complies with the ANSI Z359.11 standard and has a weight capacity of up to 310 lbs. This element was included in the final setup as it is a standard part of the gear worn by parachuters, and as such, it has the potential to have a positive influence over the sense of presence. The harness also represents the passive haptic—a physical prop that creates tactile and haptic feedback experienced by the users.

The harness is designed to be used for a short amount of time when a real fall occurs, and different forces are applied on the human body; during parachuting, for example, the straps do not put as much pressure on the legs and the rest of the body. However, being that the subject will be suspended for at least 30 minutes during the experimental session, it is mandatory to have a safe and comfortable setup. After consulting with the Naval Postgraduate School’s (NPS) Safety & Occupational Health Manager, we

arrived at the solution that included a universal-size work positioning seat, manufactured by Franklin, which supports up to 330 lbs (Figure 45).



Figure 44. Full body harness



Figure 45. Universal-size work positioning seat

The attachment of the seat and the harness to the frame structure was achieved using three non-shock lanyards (manufactured by Guardian), which comply with all the ANSI standards for fall protection and have a capacity of 310 lbs (Figure 46).



Figure 46. Lanyards used to connect the metal frame to the harness

Three 18 mm slings (loops) were used as a physical interface between the lanyards and the metal frame; each lanyard had a length of 47 in and a weight capacity of 4,900 lb (22 kN). An additional sling was used to attach the harness to the lanyard. Finally, two hooks with a weight capacity of 25 kN were used to attach the metal frame to the lanyard that connects the harness. The final elements in the physical setup for the user were two spring cords that attached the Oculus controllers to the frame to mimic the pressure applied to the parachute. Two climbing carabiners at the end of the cords attached the controller strip to the cord.

D. FULL SYSTEM INTEGRATION

The final system was reviewed and approved by both the NPS Safety & Occupational Health Manager and the Institutional Review Board (IRB) Committee.

1. Main Stand and Research Operation Station

All the acquired elements were assembled into the prototype stand designed in Chapter IV. The two main components of the system setup are the metal stand with the harness and the research operation station, or ROS. Different configurations are possible, but the one adopted for the study was developed with the help and approval of the NPS Safety & Occupational Health Manager. Figure 47 shows the configuration achieved for the harness-holding structure.

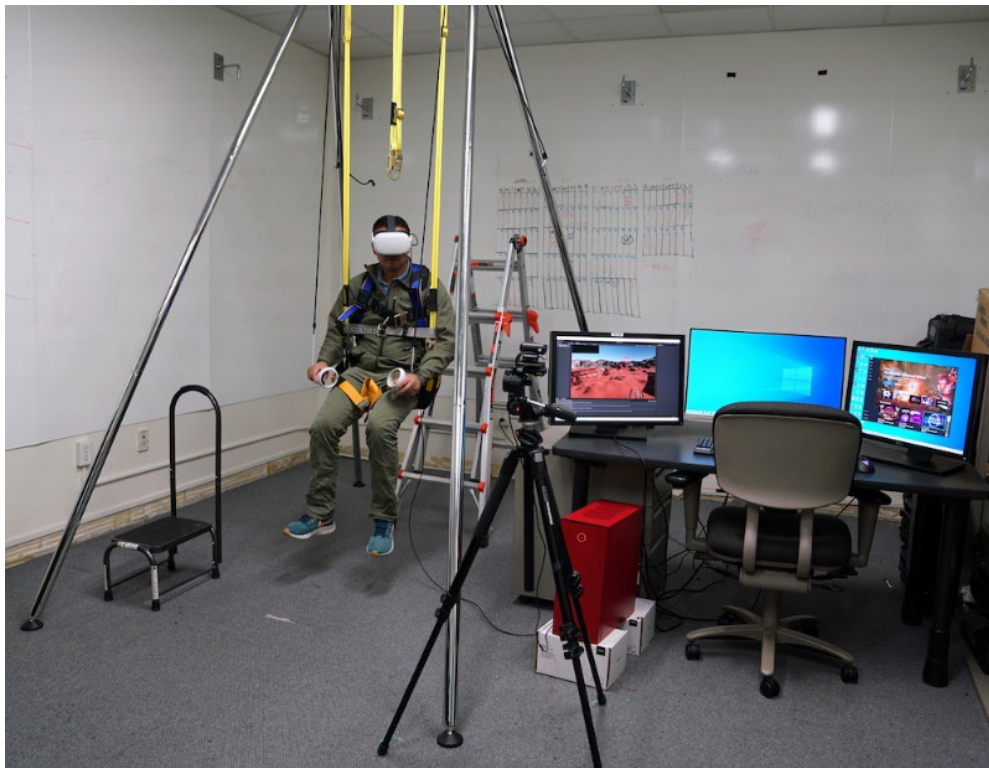


Figure 47. Final VR-PTS experimental station with the user

Another element of the hardware integration is the control operation station consisting of three monitors, one desktop computer, and one recording camera. This setup allows the operator to control the simulation from one screen and the second one to record the session for study purposes. The third monitor allows the operator to do any other task.

2. Cost Breakdown

The total cost of developing the prototype is summarized in Table 4.

Table 4. Prototype cost breakdown

Item	Cost (US dollars)
Metal Structure	\$389
Body Harness	\$185
Lanyards	\$155
Seat	\$220
Meta Quest 2	\$499
Desktop Computer	\$2000
Monitors	\$200
Stool	\$120
Loops	\$60
Total	\$3439

The approximate total cost of the whole system is 3,439 USD. The amount does not include the labor cost to develop the application.

E. CHAPTER SUMMARY

In this chapter, the functional prototype for conducting the usability study was developed. This was accomplished using different technologies, elements, and interfaces.

VI. USABILITY STUDY

A. INTRODUCTION

This chapter presents the design, execution, and results of the user study that evaluates the usability of the resulting prototype system. One part of the study focused on users' ability to evaluate heights (altitudes) while executing virtual parachute jumps. That type of result would be very relevant to the parachuting task in the military and civilian context.

B. STUDY DESIGN

The study design is one of the most important parts of this work, to test the feasibility of the study.

1. Institutional Review Board

Before any study, the Naval Postgraduate School requires all research involving human subjects to be reviewed and approved by the IRB. This process requires submission of the following documentation: IRB application, scientific review form, conflict of the interest disclosure form, informed consent form, recruitment flyer, recruitment email, simulator sickness questionnaire (SSQ), demographic questionnaire, system usability scale (SUS) questionnaire, post-task questionnaire, and approved thesis proposal. The start of the usability study was approved in April 2023 (Appendix E).

2. User Task

Once the subject is positioned in the seat, has a headset on, and holds the hand controllers, the virtual experience that consists of multiple jumps can start.

For each environment (virtual terrain), each subject participates in the same procedure:

Pre-evaluation stage (pre-test): Without prior training, the subject is presented with the first virtual environment and asked to guess the 300 m and 5 m heights on a single jump; the study brief read by the subject at the beginning provides information about the

task and heights the study is interested in, and the same information is repeated orally before the pre-test, just to make sure subjects remember significant heights. The objective of this single jump is to have a baseline evaluation to compare against evaluations during the test stage and identify any improvement in precision of that evaluation. The tasks associated with those two heights are:

Task 1: Identify the height corresponding to the altitude when the subject must start making the final approach to land (300 m / 1,500 feet).

Task 2: Identify the height corresponding to the altitude when the subject would be expected to start entering the flare stage (5 m / 15 feet).

Training stage: The subject experiences three parachute jumps during which the information about the correct heights is presented in real time, i.e., it is displayed inside the headset in the frontal part of the subject's field of view throughout the fall. Our two heights of interest (final approach altitude/height and flare stage altitude/height) are highlighted with proper text and flash when those heights are reached, and the subject is asked to press the button on any hand controller to practice that action.

Evaluation stage (test stage): The subject experiences three parachute jumps during which there is no information about the correct heights displayed inside the headset. A pseudo-random location and altitude are selected for each jump. The subject is asked to look around and signal to the system (press any button on any hand controller) when, in his or her estimation, the final approach altitude/height and flare stage altitude/height are reached.

3. Participants

Participants were recruited from amongst the NPS students, faculty, and staff. The experiment was performed at the MOVES Institute at NPS in Monterey, CA, in the Watkins building, room number 212A, from May 1 to May 12, 2023. The study was widely announced through diverse ways like the NPS muster page, flyers, and emails.

4. Materials

The experimental setup with the subject is shown in Figure 48 (the experimenter plays the role of the subject for this photo). Full information about the hardware and software environments was detailed previously in Chapter V.

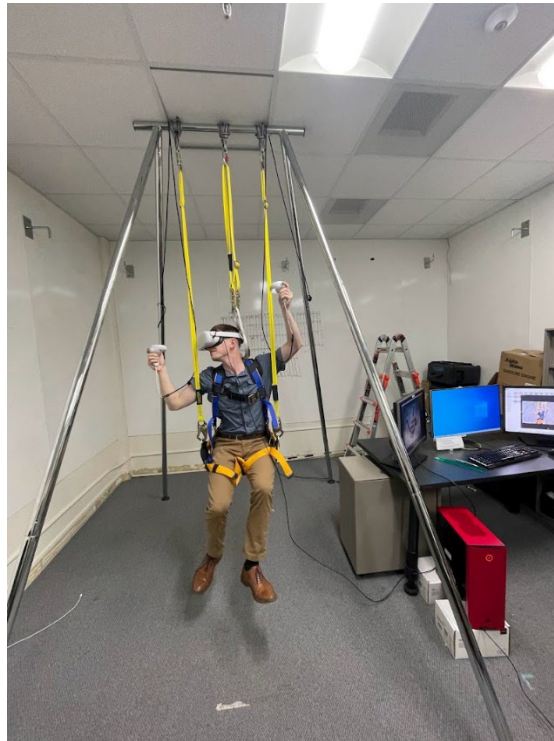


Figure 48. Subject during the research task evaluation

5. Data Collection Plan

All questionnaires filled in by the subject were realized using the Qualtrics software application; the only exception was the informed consent that was read and signed on the hard copy paper.

The data sets collected about and from each subject included:

- Objective data set: timestamped system logs about all events and user actions.

- Subjective data set: SSQ, SUS, post-task questionnaire, and demographics data.

6. Procedure

Each subject underwent the following procedure:

1. Preparation for participation in the study: Upon arriving at the research location, each subject received and read a brief about the study and the experiences he or she will go through. The subject was asked to read the terms of the informed consent. After signing that document, the individual was introduced to the functionality of the HMD Oculus Quest 2, how to use the hand controllers, and what to do if he or she began to feel the symptoms of cybersickness.
2. Baseline SSQ: The subject was asked to fill in a baseline simulator sickness questionnaire (Appendix A).
3. Getting into the seat: Next, the subject put the harness on, climbed one or two steps on the front side of the ladder, and with the help of the experimenter who was on the other side of the ladder, was helped into position in the seat. The experimenter who was on one side of the ladder attached the loop that holds the harness to the lanyard suspended on the metal structure. Depending on the person's height, the subject was positioned in the seat with his or her feet approximately 1 ft above the floor. The experimenter moved the ladder away and helped the subject close the safety belt that goes around the lanyards that hold the seat and the subject's body. The subject was then helped to don a headset and grab hold of the hand controllers. This is the position in which the subject is to execute all elements of the virtual session: pre-evaluation, training, and evaluation stages.
4. Pre-evaluation stage (pre-test), Terrain #1. A full description is provided earlier in the User Tasks section.

5. Training stage, Terrain #1. A full description is provided earlier in the User Tasks section.
6. Evaluation stage (test stage), Terrain #1. A full description is provided earlier in the User Tasks section.
7. Second set: Subjects were asked to take a short break, and the pre-evaluation (pre-test), training, and evaluation (test) stages were repeated for Terrain #2.
8. Dismount from the seat: The experimenter helped the subject get out of the seat and harness.
9. Post-task SSQ: Subjects filled out the second SSQ questionnaire.
10. SUS questionnaire: Subjects filled out the SUS questionnaire (Appendix B).
11. Post-task questionnaire: Subjects filled out the post-task questionnaire (Appendix C).
12. Demographics questionnaire: Subjects filled out the demographic's questionnaire (Appendix D).
13. Post-study debrief: Subjects were debriefed about the purpose of the study and allowed to ask any questions related to their participation in the study.

7. Statistical Analysis Plan

First, a simple descriptive analysis was made to compare whether there was an improvement in the height estimation before (at the pre-evaluation) and after the training evaluation for both the final and flare heights of the grassland and desert virtual environments.

A t-statistical test was performed on every height assessment for each environment. The null hypothesis assumed that there is no statistical significance between the ideal correct environment height to the flare or the final approach and the respective heights

chosen by the subjects, while the alternative hypothesis was that there is a significant statistical difference in the chosen heights. In other words:

1. Null Hypothesis (H0): There is no significant difference between the mean height chosen by the 30 people in virtual reality and the theoretically correct height of 5 m.
2. Alternative Hypothesis (H1): There is a significant difference between the mean height chosen by the 30 people in virtual reality and the theoretically correct height of 5 m.

The next step was the data collection. The data was recorded during the study procedure and was standardized in meters, but subjects can choose to be trained in both meters and feet depending on the units of measurement they are used to. Then all the descriptive statistics were calculated; the sample mean, and the sample standard deviation(s) of the heights chosen by the 30 people.

The following phase set a significance level (α) for the experiment; in this case the significance level was 0.05, which corresponds to a 5% level of significance and calculates the t-test statistic with the formula:

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

where \bar{x} is the sample mean, μ is the theoretical correct height (5 m), s is the sample standard deviation, and n is the sample size.

Then, the P-value was associated with the calculated t-test statistic. This can be done using a t-table or statistical software. If the t-test statistic falls in the critical region, then we can reject the null hypothesis and conclude that there is a statistical significance between the mean height chosen by the 30 people in virtual reality and the theoretically correct height of 5 m. Otherwise, if the calculated t-test statistic does not fall in the critical region or the P-value is greater than the chosen significance level (α), then we would fail to reject the null hypothesis.

Then a two-sample t-test was performed to compare the heights chosen by the subjects in the two different environments (grassland and desert) during the virtual reality jumping experiment at both the flaring and final approach height and tested the following hypotheses:

1. Null Hypothesis (H₀): There is no difference in the heights chosen by people in grassland and desert environments during the virtual reality jumping experiment.
2. Alternative Hypothesis (H_a): There is a difference in the heights chosen by people in grassland and desert environments during the virtual reality jumping experiment.

8. Physical Environment

The study was made in a closed and controlled environment in the Modeling Virtual Environments and Simulation (MOVES) Institute at NPS, in laboratory number 212 (Watkins building). The subject was suspended in a harness with his or her feet approximately 14 in above the ground and holding both the Oculus Quest and two controllers in the setup built and explained in Chapter V.

9. Virtual Terrains

The study consisted of two synthetic terrain environments, grassland and desert. Each had a training environment with an altimeter and a visual notification identifying the final approach and flare heights. A set of several predefined jump altitudes, jump locations, and landing areas at each jump were selected from that set.

The jump height was always between 400 m and 600 m. The height was equal to the horizontal distance (400 m to 600 m) to the target (landing) area to draw a 45-degree cone because the airspeed was equal to the ground speed, and the vertical speed was the same as the horizontal speed. The former is true because, in the present study, the wind factor was omitted. Figure 49 shows the landing process.

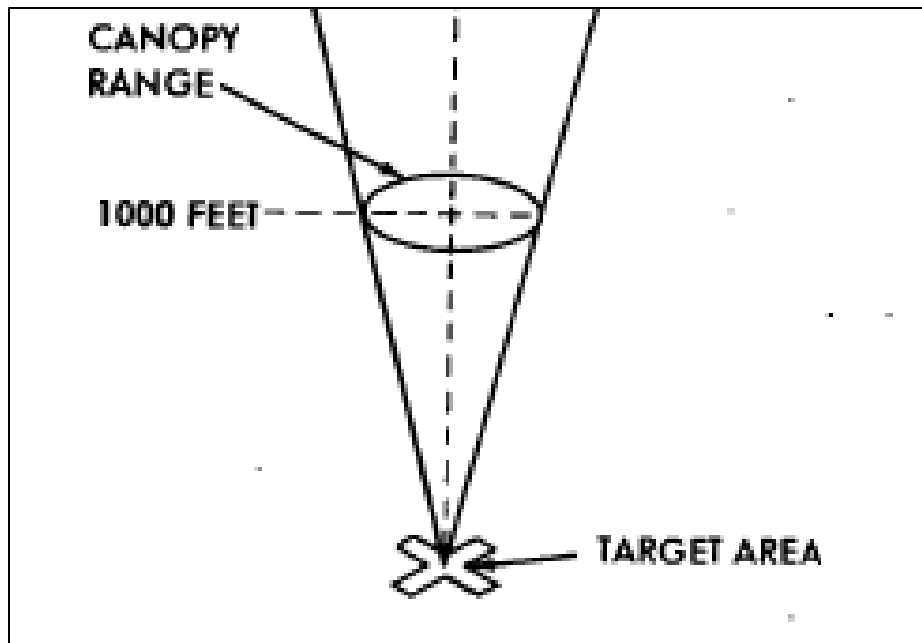


Figure 49. Cone landing path

C. RESULTS

In the following subsections the result from the study will be discussed.

1. Demographic Data

The usability study involved 31 participants: 3 females and 28 males. The subjects ranged from military to civilian personnel, and all participants but one who started the study finished it.

Figure 50 shows the plot of the age histogram of the participants, and Table 5 shows the descriptive statistics from the study population.

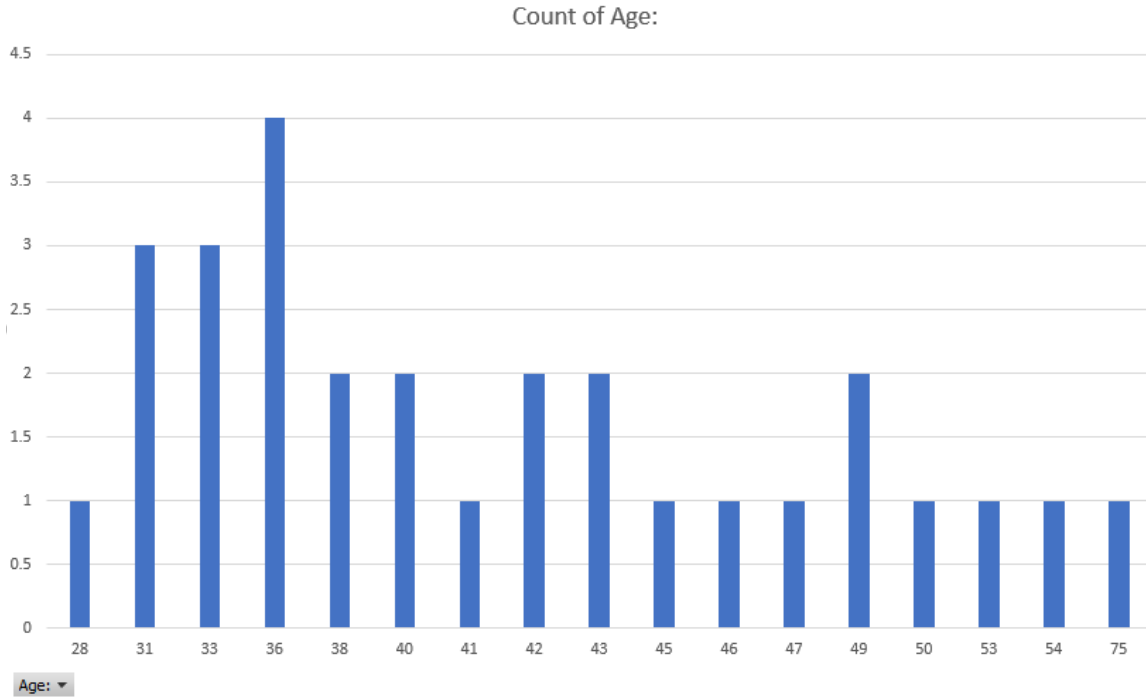


Figure 50. Subject's age histogram

Table 5. Subjects' descriptive statics summary

Age	
Average	41.34
Minimum	28
Maximum	75
Standard Deviation	1.77

2. Quantitative Data

The objective data set included system logs in meters for each subject's jumps during the virtual sessions. The data was analyzed using the data analysis tool from

Microsoft Excel software and acquired, recorded, saved, and retrieved using the Qualtrics platform provided by NPS.

a. Pre-evaluation versus Evaluation Analysis

A comparison of the descriptive statistics can be found in Table 6.

Table 6. Descriptive statistics comparison from the pre-evaluation and evaluation stages; all numbers are in meters

	Grassland			Desert		
	Average	SD	Min – Max	Average	SD	Min – Max
Pre-Evaluation Flare	15.21	8.38	1.50–31.60	12.83	7.45	2.30–38.40
Evaluation Flare	10.27	6.71	1.60–30.60	9.40	6.10	2.30–27.60
Pre-Evaluation Final	340.87	80.20	220.00–500.00	315.32	66.85	220.00–504.00
Evaluation Final	285.10	22.25	228–320	266.40	34.30	201.00–328.00

Analyzing the flaring data in more detail, we can see that at the very first evaluation, the jump in both environments has the best result. Then, as the evaluation continues, we can see that the height selected for the flare starts to increase again, the third one with the highest value chosen. We can see this in the graph shown in Figure 51.

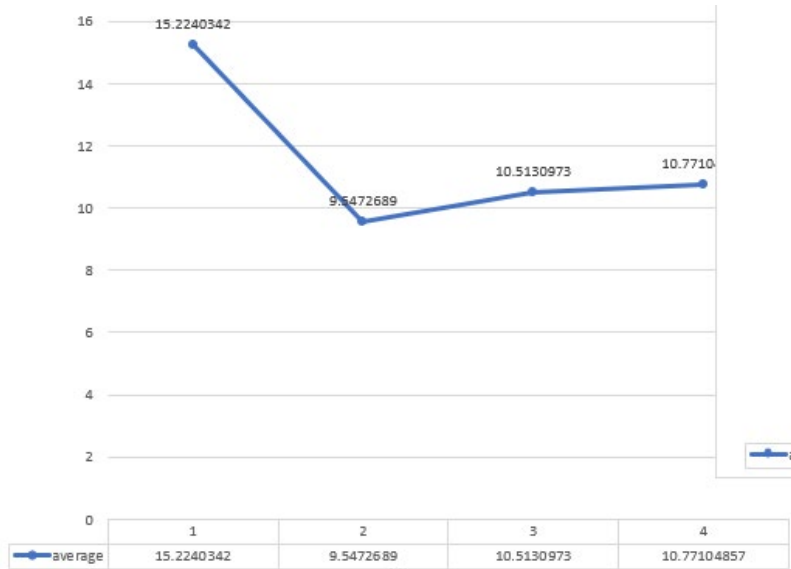


Figure 51. 5 m height grassland evaluation evolution

Interestingly, with the final approach height, as the evaluation goes on, every time the subjects choose a lower and lower height, until the third evaluation is the one with the lowest chosen. Figure 52 graph shows this behavior.

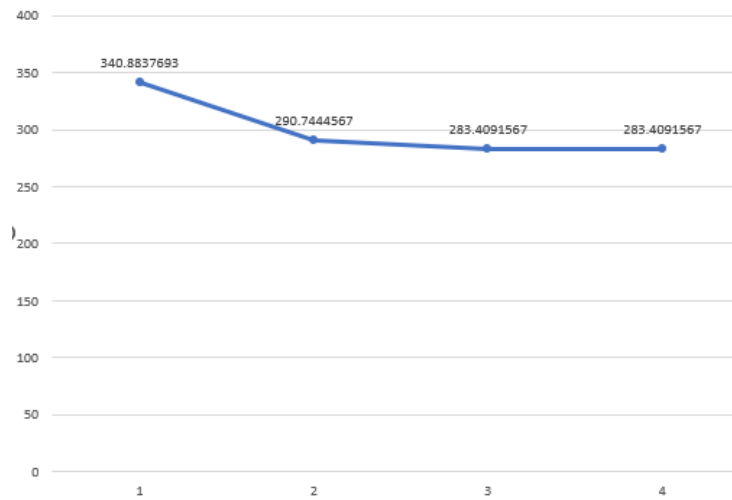


Figure 52. 300 m height evaluation evolution

To find out if there is a significant difference after the training, a two-tail t-test for paired means among two samples was performed with a significance level of 0.05, being the null hypothesis that the sample means before and after the training is the same and the alternate hypothesis that there is a statistical difference, i.e., the training worked. The results can be found in Tables 7 through 10.

Table 7. 5 m statistical test result for grassland environment

	Pre-evaluation	Evaluation
Mean	15.22	10.27
Variance	70.33	45.14
Observations	30	30
Hypothesized Mean	0	
Df	29	
t Stat	3.06	
P(T<=t) two-tail	0.0047	
t critical two-tail	2.04	

Table 8. 5 m statistical test result for desert environment

	Pre-evaluation	Evaluation
Mean	12.83	9.16
Variance	55.54	51.96
Observations	30	30
Hypothesized Mean	0	
Df	29	
t Stat	1.94	
P(T<=t) two-tail	0.061	
t critical two-tail	1.699	

Table 9. 300 m statistical test result for grassland environment

	Pre-evaluation	Evaluation
Mean	340.87	290.74
Variance	6434.42	1330.25
Observations	30	30
Hypothesized Mean	0	
Df	29	
t Stat	3.61	
P(T<=t) two-tail	0.0011	
t critical two-tail	1.70	

Table 10. 300 m statistical result for desert environment

	Pre-evaluation	Evaluation
Mean	315.32	274.40
Variance	4469.07	1674.10
Observation	30	30
Hypothesized Mean	0	
Df	29	
t Stat	2.64	
P(T<=t) two-tail	0.013	
t Critical two-tail	1.699	

The analysis suggests that the t-statistical result is always more significant than the critical value, so we reject the null hypothesis for the four cases. In other words, there is a significant difference between the data before and after the training. i.e., there is an improvement in the height estimation.

b. Statistical Test for Grassland versus Desert

A two-sample t-test assuming unequal variances was performed to ensure that the means in both environments are equal or different, as the null hypothesis is that both environments have the same means, and the alternative hypothesis is that they are different. Tables 11 and 12 show the results of those analyses.

The results suggest that for the 5 m height evaluation, there is no difference in the height chosen in both environments. On the other hand, the results reveal a significant difference in the height chosen in the 300 m evaluation. In other words, the 300 m height evaluation in the grassland had a better estimation.

Table 11. Statistical results from the 5 m height evaluation in both environments

	Grassland	Desert
Mean	10.27	9.41
Variance	45.14	38.12
Observation	30	30
Hypothesized Mean	0	
Df	58	
t Stat	0.51	
P(T<=t) two-tail	0.60	
t Critical two-tail	2.00	

Table 12. Statistical results from the 300 m height evaluation in both environments

	Grassland	Desert
Mean	285.85	265.89
Variance	495.17	1138.07
Observation	30	30
Hypothesized Mean	0	
t Stat	0.51	
P(T<=t) two-tail	0.009	
t Critical two-tail	2.00	

c. T-Statistical Test Chosen Heights versus Virtual World Height

For the flare height (5 m) evaluation, a one-sample t-test with 29 degrees of freedom was performed in both environments (grassland and desert); we wanted to test whether there was a statistically significant difference between the mean of the average tree jump per subject and the expected correct training height of 5 m. Table 13 and Table 14 show the results found in both environments.

Table 13. Grassland 5 m statistical test results

Mean	10.27
Variance	45.14
Observation	30
Hypothesized Mean	5
Df	29
t Stat	4.29
P(T<=t) two-tail	0.0001
t Critical two-tail	2.04

Table 14. Desert 5 m statistical test results

Mean	9.40
Variance	38.12
Observation	30
Hypothesized Mean	5
Df	29
t Stat	3.91
P(T<=t) two-tail	0.0005
t Critical two-tail	2.04

The same idea was applied to the data results from the height estimation of 300 m, with the same significance level of 0.05, and again with a two-tail one-sample t-test performed on the data. The results are shown in Tables 15 and 16.

Table 15. Grassland 300 m statistical test results

Mean	285.85
Variance	495.17
Observation	30
Hypothesized Mean	300
Df	29
t Stat	-3.48
P(T<=t) two-tail	0.001
t Critical two-tail	2.04

Table 16. Desert 300 m statistical test results

Mean	266.49
Variance	1180.98
Observation	30
Hypothesized Mean	300
Df	29
t Stat	-5.33
P(T<=t) two-tail	0.0001
t Critical two-tail	2.04

We can see that in both the 5 m and 300 m evaluations in each virtual environment, the t-statistics are bigger than the t critical. In other words, there is a statistically significant difference between the height mean chosen by the subjects and the hypothesized height of 5 m. Hence, there is no evidence that the subjects chose the correct virtual height in either environment or at either height.

3. Qualitative Data

The subjective information was collected via the questionnaires implemented in the Qualtrics data collection tool. The proctor applied data analysis as defined by Brooke (1996) for the SUS questionnaire and Kennedy (1993) for the SSQ questionnaire.

a. *Simulator Sickness Questionnaire (SSQ)*

There were two times when the SSQ was given to the participants (Appendix A); before being suspended in the harness (baseline SSQ) and at the end of the entire virtual session (pre-evaluation, training, and evaluation for both virtual environments), the post-task SSQ.

The symptoms listed in SSQ questionnaire (17 in total) are divided into three categories: nausea, oculomotor, and disorientation; each category is assigned different weights. According to Kennedy (1993), symptoms between 5 and 10 suggest minimal symptoms, and that SSQ interval is where the results from our study fall (Table 17).

Table 17. Average results from SSQ scales

Scale	Result
Nausea	7.55
Oculomotor	8.84
Disorientation	6.38
Average	7.59

The baseline SSQ results can be seen in the graph displayed in Figure 53.

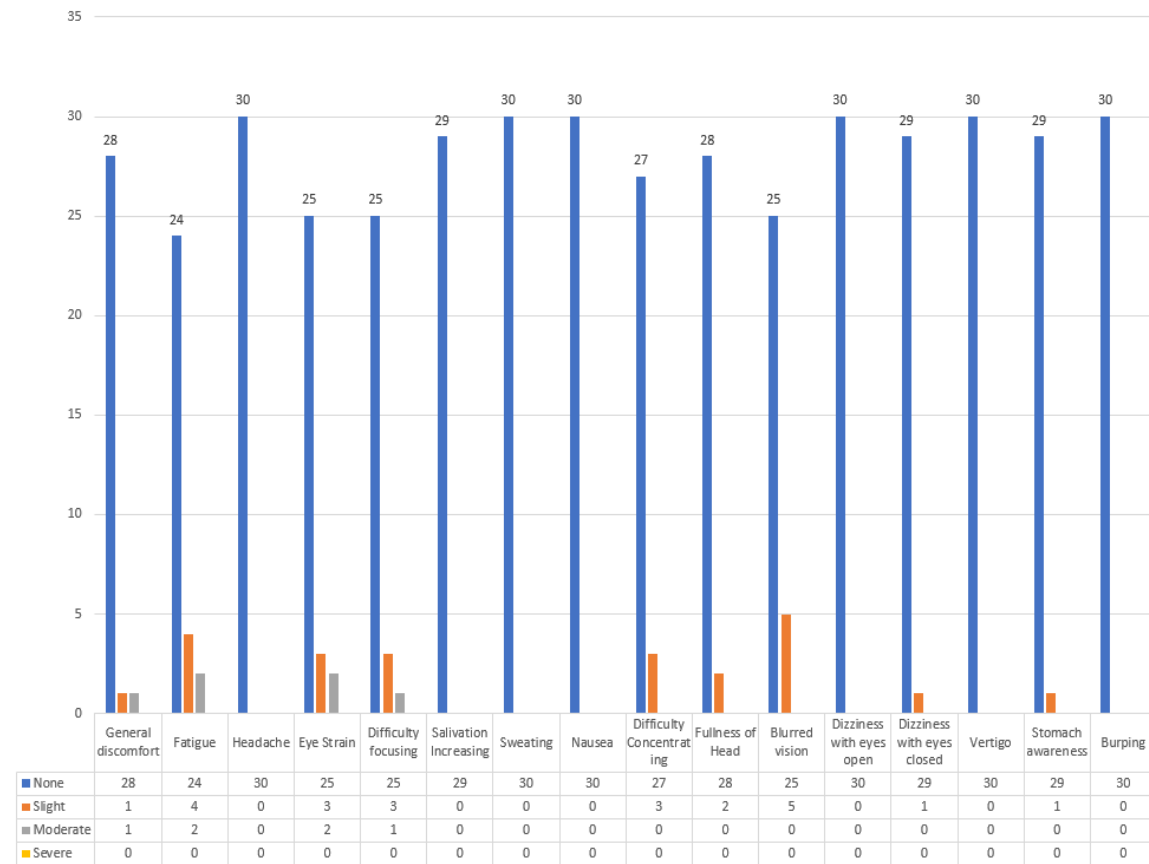


Figure 53. Baseline SSQ (before the study)

To analyze the symptoms of the subjects after the experiment, a Post-Task SSQ questionnaire was completed. Figure 54 shows the Post-Task SSQ results from the study. The insights that we can get from the data is that *general discomfort* was increased to slight

in 11 people, eight people changed from ‘no nausea’ to ‘slight’ values, six people reported *eye strain* at the ‘slight’ value, and five people reported ‘slight’ *fatigue* after the virtual session.

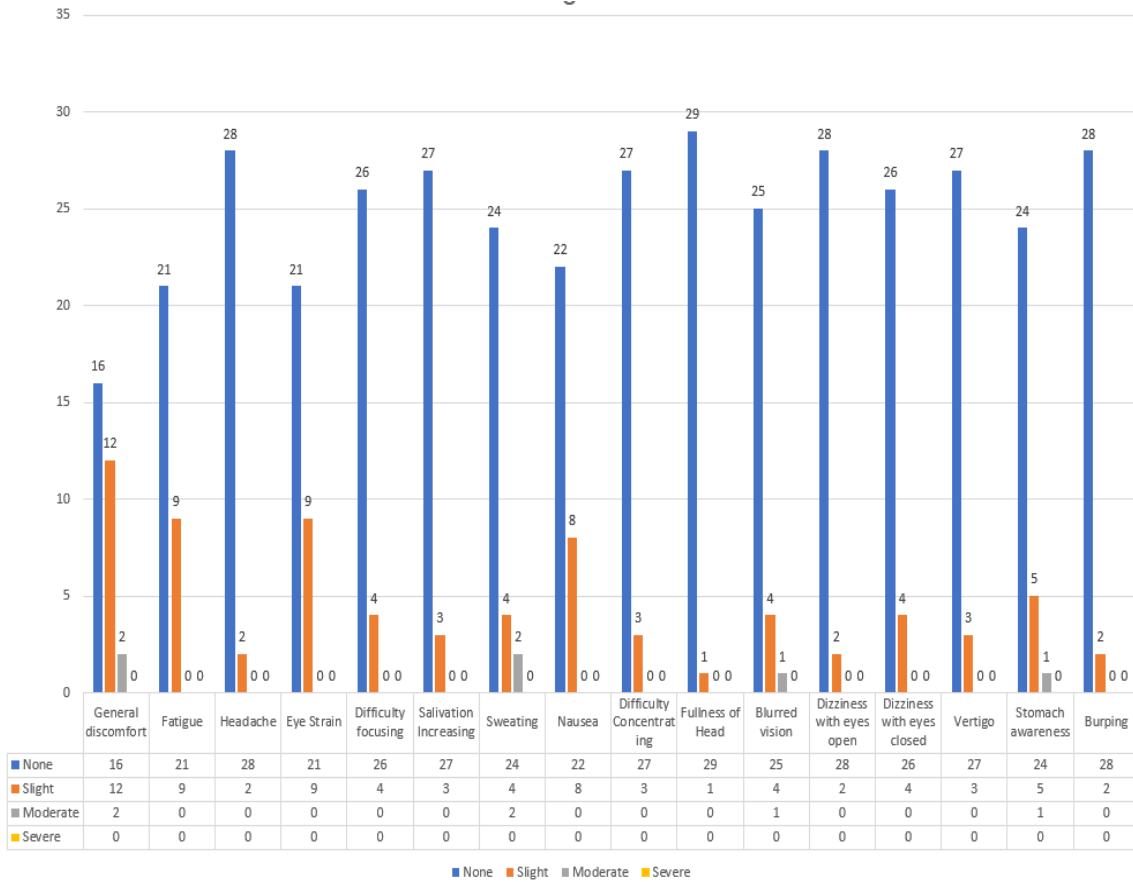


Figure 54. Post-Task SSQ (after evaluation)

b. System Usability Scale (SUS)

The SUS helps determine the degree to which the system (here the parachute prototype system) can be helpful and if it is appropriate in the given framework (here the parachuting framework) (Kennedy, 1993). In our context, we want to see the potential for adapting and including this type of solution in a more comprehensive parachuting trainer. SUS questions were asked with a qualifiable level ranging from one (Strongly Disagree) to five (Strongly Agree); the calculation of the final score followed the instructions

presented in Kennedy (1993). The results presented in Table 18 suggest that the system got an average of 78.89, which means that the system's overall usability was declared by the subjects to be good.

Table 18. SUS score results

SUS-Score	Grade	Adjectival Rating
>80.3	A	Excellent
68-80.3	B	Good
68	C	Okay
51-68	D	Awful
<51	F	Poor

Average	78.89
Min	47.5
Max	100
StdDev	14.89

Figure 55 and 56 shows the graph that represents the number of answers for every one of the ten questions asked in the SUS.

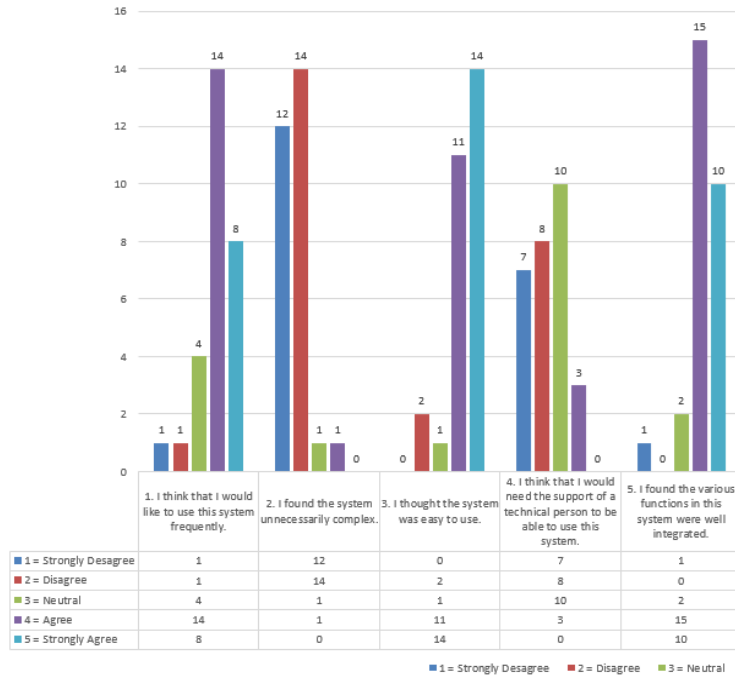


Figure 55. SUS results

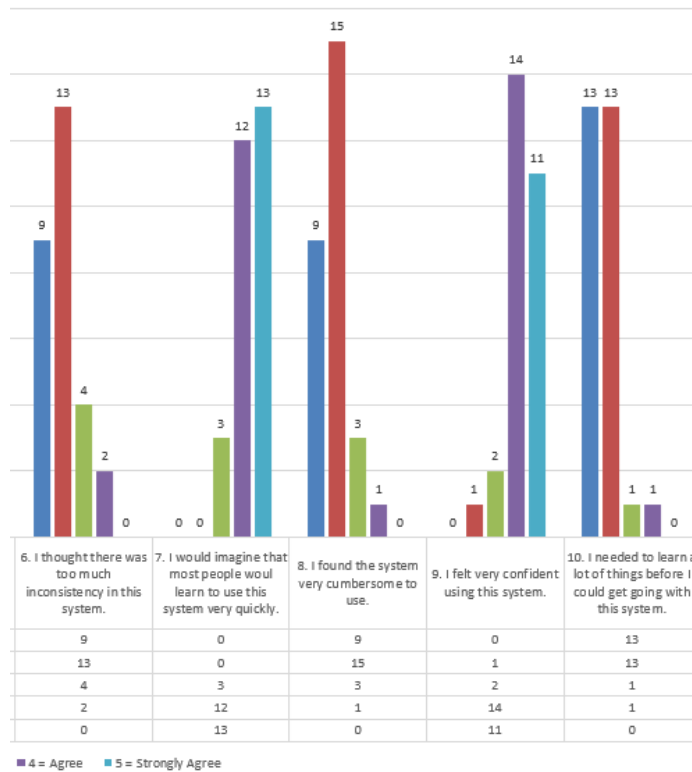


Figure 56. SUS Results

c. Post-Task Survey

The post-task survey consisted of 12 questions; the goal was to acquire additional insight about the characteristics of the virtual environment presented in the prototype system. A total of nine questions were asked on a scale from one (on the negative end) to seven (at the positive end), and three were open-ended questions that allowed the participants to express their thoughts about the system.

Figure 57 shows the bar graph that summarizes the responses made by the subjects.

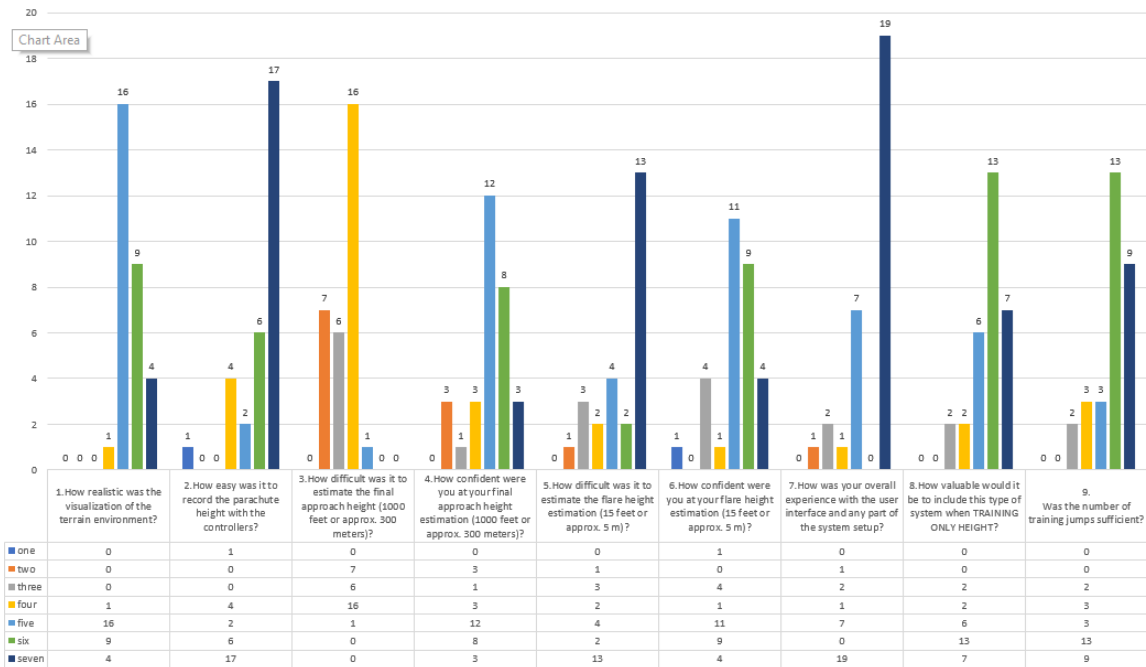


Figure 57. Post-task survey responses summary

Table 19 shows the descriptive statistics for each question asked in the post-task survey. Data suggest that the subjects felt more confident when evaluating flare height (5 m) than in the final approach height (300 m). The questions for which responses had the best score were related to the use of the input device (question #2) and estimation of the flare height (question #5). Another question that got a relatively high score was the user experience with the rest of the system setup (question #8).

Table 19. Post-task results descriptive statistics

Question	Average	Minimum	Maximum	SD
How realistic was the visualization of the terrain environment?	5.53	4	7	0.77
How easy was it to record the parachute height with the controllers?	6.06	1	7	1.43
How difficult was it to estimate the final approach height (1000 feet or approx. 300 meters)?	3.36	2	5	0.88
How confident were you at your final approach height estimation (1000 feet or approx. 300 meters)?	5	2	7	1.36
How difficult was it to estimate the flare height estimation (15 feet or approx. 5 m)?	6.06	2	8	1.74
How confident were you at your flare height estimation (15 feet or approx. 5 m)?	5.13	1	7	1.40
How was your overall experience with the user interface and any part of the system setup?	6	2	7	1.48
How valuable would it be to include this type of system when training only height?	5.7	3	7	1.11
Were the number of trainings jumps sufficient?	5.8	3	7	1.14
Average	5.4			

The analysis of the answers to open-ended questions provided us with the following insights:

- Most people used the mountains and the trees to estimate the height, but some people also used the horizon.
- Simulation should be ‘frozen’ at significant heights to have more time and acquire better situational awareness of the surroundings, in part because the falling time was too short to see the details of the surrounding area.
- The realism of the environment should be increased.
- There should be an announcement for the starting altitude of every jump.
- The swing and the seat should be fixed.
- People who had previously parachuted emphasized the utility of one part-task training; even though they may have a hand altimeter most of the time, they do not look at it because they observe the surroundings to avoid any obstacle that may cause an injury when landing.
- This was a useful proof of concept that could help save money for the military.

D. PROTOTYPE LIMITATIONS

We identified several limitations to the prototype; they can be classified as limitations of the physical setup and system hardware and limitations of the software solution.

Limitations of the physical setup and system hardware include:

- The realism of the haptics could be further improved.
- The pressure the subject must exert on the controllers acting as toggles is not calibrated to be realistic.
- Future solutions to the system should have headsets with better resolution and FOV. The headset used in our study had a resolution of 1832 x 1920 pixels per eye (full HD). Also, the horizontal and vertical FOV of the

Oculus is 100 and 90 degrees, respectively, which is significantly smaller than the FOV of the human eye (140 degrees horizontally and 160 degrees vertically).

- The resulting framerate could be improved: The framerate drops on average from 120 on the PC to 60 frames per second (fps) when the HMD is connected to the PC via the Oculus Link. The HDM introduces the latency; images need to be transferred to the headset, and head and hand tracking also takes additional processing power. The lower framerate can also influence the symptoms of cybersickness, so ideally, the effort should be invested to make the framerate remain constant during the runtime and at the higher level.

E. SUMMARY

This chapter presented the elements of the user study focused on the usability of the developed prototype system. One part of the study was focused on users' ability to evaluate heights (altitudes) while executing virtual parachute jumps. This type of investigation allows us to gain insight into the degree to which VR can be used to provide training in parachuting skills. While optimal training was not achieved, we can conclude that an underestimation of the horizontal distance previously observed by many researchers was also identified by this study for cases of higher vertical heights.

VII. CONCLUSION, RECOMMENDATIONS, AND FUTURE WORK

A. CONCLUSIONS

The following subsections address some of the most important findings in this work.

1. Addressing the Research Questions

Let us first address research questions posed at the beginning of this research effort.

1. What is the feasibility of developing a low-cost prototype that employs COTS, immersive VR technology and passive haptics in support of parachute landing process?

Our experience in designing and developing the prototype system suggests that it is possible to build the system using only COTS solutions. The responses of the subjects in the user study (reflected in the SUS scores) suggest that the part-task virtual reality parachute system prototype would be adequate to provide initial insights into the parachuting task. Many subjects reported that the sensation in the final section of the jump was very similar to that of almost hitting the ground, and instinctively, some of them retracted their legs as if to prepare for touching the ground.

Furthermore, some people who had experience of the traditional parachuting course saw a potential use for this type of solution. They explained that it would be positive if they had been trained with a solution like this before their first real jump.

2. To what extent does VR enhance height situational awareness for a paratrooper?

The results of the statistical test confirm that, like previous research focused on evaluation of the horizontal distances in virtual environments, the errors in distance estimation in vertical height judgment are also present.

For example, in the case of the height of 5 m, the overestimation factors were practically doubled in both environments, with averages around 10 m. On the other hand,

in case of the height of 300 m, there was underestimation by a factor of 0.95 in the grassland and 0.87 in the desert environment. The results suggest that this prototype may be better suited to train at higher altitudes than lower altitudes; the case of lower heights would need to be given additional attention and be further investigated.

B. RECOMMENDATIONS AND DOMAIN CONTRIBUTIONS

Among the many recommendations that can be made, the most important one is to increase and vary the number of training jumps before the evaluation. As advised by some subjects, it may be beneficial to ‘freeze’ the subject’s viewpoint for a certain amount of time and examine whether that increases the accuracy of height estimation with the help of an instructional designer.

Another important recommendation is to experiment without changing the flying path and by maintaining the same jump start height to observe any pattern in the study. It would also be essential to increase the fidelity of the environment and introduce better shadows and textures.

The main contribution of this work is our understanding that it is possible to develop a low-cost parachute trainer that can be meaningful in the training process. This work also demonstrated that even though the training process had a positive and significant effect on height estimation, the approach used in the study needs to be further improved if it is to be used for training the subject in performing height estimation with better accuracy, especially in case of the lower height (5 m in this study).

The study also showed that the number of visual clues provided in the synthetic environment significantly influenced the accuracy of estimating the correct height. In other words, the higher number of trees and more abundant vegetation in the grassland, the greater the confidence in subjects’ correct height selection.

C. FUTURE WORK

Several avenues are recommended for the future work. The first would be to increase the number of synthetic environments that would be tested to get new insights on the influence that different environments make on height estimation. Another suggestion

would be to increase the fidelity of the parachute aerodynamics with more realistic behavior. Further, including the wind as a study variable could increase the realism and overall usability of the system.

Additionally, the same system could be built using different game engines and more advanced rendering technology, such as Unreal Engine 5, with the goal of creating a more realistic environment. Likewise, future studies would benefit from having an HMD with more advanced technical specifications such as the FOV, resolution or FPS. Additional optimizations of the setup could include adding a fan to simulate the wind, introducing some type of solid platform subjects could experience under their feet when they touch the ground in the virtual environment, and using a harness with better ergonomics to eliminate the use of the seat. Such changes would most likely increase the cost of the system, but that increase would not be too significant.

Furthermore, military personnel with parachuting backgrounds (the expert users) should be tested to get their feedback and investigate how this type of system can be used to improve current training approaches.

Finally, we recommend expanding this system to build a more comprehensive solution that could serve as a basis for the training of paratroopers in the jump school.

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APPENDIX A. SSQ

No _____

Date _____

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

- | | | | | |
|--------------------------------|-------------|---------------|-----------------|---------------|
| 1. General discomfort | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 2. Fatigue | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 3. Headache | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 4. Eye strain | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 5. Difficulty focusing | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 6. Salivation increasing | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 7. Sweating | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 8. Nausea | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 9. Difficulty concentrating | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 10. « Fullness of the Head » | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 11. Blurred vision | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 12. Dizziness with eyes open | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 13. Dizziness with eyes closed | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 14. *Vertigo | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 15. **Stomach awareness | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |
| 16. Burping | <u>None</u> | <u>Slight</u> | <u>Moderate</u> | <u>Severe</u> |

* 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.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, 3(3), 203-220.

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APPENDIX B. SUS

Subject ID: _____
Date: _____

SUS Questionnaire

**Please reflect and answer the following question based on your experience with the system in this study.*

1. I think that I would like to use this system frequently:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

2. I found the system unnecessarily complex:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

3. I thought the system was easy to use:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

4. I think that I would need the support of a technical person to be able to use this system:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

5. I found the various functions in this system were well integrated:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

6. I thought there was too much inconsistency in this system:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

7. I would imagine that most people would learn to use this system very quickly:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

8. I found the system very cumbersome to use:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

9. I felt very confident using the system:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

10. I needed to learn a lot of things before I could get going with this system:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
-------------------	----------	---------	-------	----------------

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APPENDIX C. POST-TASK QUESTIONNAIRE

Subject ID: _____

Date: _____

1. How realistic was the visualization of the terrain environment?

1	2	3	4	5	6	7
Not very realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	realistic	Very realistic

2. How easy was it to steer the parachute?

1	2	3	4	5	6	7
Not easy at all	Not easy	Somewhat not easy	Neutral	Somewhat easy	Easy	Very easy

3. How difficult was it to estimate the *final approach height* (1000 feet or approx. 300 meters)?

1	2	3	4	5	6	7
Very difficult	Moderately difficult	Somewhat difficult	Neutral	Slightly easy	Moderately easy	Very easy

4. How confident were you at your *final approach height* estimation (1000 feet or approx. 300 meters)?

1	2	3	4	5	6	7
Not very confident	Not confident	Somewhat not confident	Neutral	Somewhat confident	confident	Very confident

5. Was there something that influenced your level of confidence with the *final approach height* estimation (1000 feet or approx. 300 meters)?

- a. _____
- b. _____
- c. _____

6. How difficult was it to estimate the *flare height* estimation (15 feet or approx. 5 m)?

1	2	3	4	5	6	7
Very difficult	Moderately difficult	Somewhat difficult	Neutral	Slightly easy	Moderately easy	Very easy

7. How confident were you at your *flare height* estimation (15 feet or approx. 5 m)?

1	2	3	4	5	6	7
Not very confident	Not confident	Somewhat not confident	Neutral	Somewhat confident	confident	Very confident

8. Was there something that influenced your level of confidence with the flare height estimation (15 feet or approx. 5 m)?

- a. _____
- b. _____
- c. _____

9. How was your overall experience with the user interface and any part of the system setup?

1	2	3	4	5	6	7
Very difficult	Moderately difficult	Somewhat difficult	Neutral	Slightly easy	Moderately easy	Very easy

a. If there was any issues, please explain what they were:

- 1. _____
- 2. _____
- 3. _____

10. How valuable would it be to include this type of system when training parachuting skills?

1	2	3	4	5	6	7
Not very valuable	Not valuable	Somewhat not valuable	Neutral	Somewhat valuable	Valuable	Very valuable

11. Before you were asked to estimate the heights, you were provided with several training jumps when the information about the actual height was presented inside the headset.

Was the number of training jumps sufficient?

1	2	3	4	5	6	7
Not very sufficient	Not sufficient	Somewhat not sufficient	Neutral	Somewhat sufficient	Sufficient	Very sufficient

a. If you were to suggest any changes to that training, please explain what they would be:

- 1. _____
- 2. _____
- 3. _____

12. Additional comments and remarks:

APPENDIX D. DEMOGRAPHICS QUESTIONNAIRE

Parachuting Task

Subject ID: _____

Date: _____

- |
1. Year of Birth: _____
 2. Years of Service: _____
 3. Current Rank: _____
 4. Designator: _____
 5. Gender: M / F
 6. Are you colorblind?
YES NO
 7. Do you play video games?
YES NO
 - a. If "YES":
 - i. How often? (select one that applies)
 - a. ___ Less than 2 hrs/wk
 - b. ___ 2-4 hrs/wk
 - c. ___ 4-8 hrs/wk
 - d. ___ More than 8 hrs/wk
 - ii. What percentage of each game type do you play? *Ensure that both values add to 100%.*
single-player _____ % multi-player _____ %
 8. Have you used virtual reality or augmented reality head mounted displays before?
YES NO
 - a. If 'YES':
 1. What kind? (select all that apply)
 - a. ___ HTC Headsets
 - b. ___ Oculus Quest
 - c. ___ Valve Index
 - d. ___ Hololens 1 or 2
 - e. ___ Large simulators (example: ship or aircraft simulators)
 - f. ___ Other: _____
 2. How many times in the last 5 years? (select one that applies)
 - a. ___ Only once
 - b. ___ Less than 5 times
 - c. ___ Between 5 and 10 times
 - d. ___ More than 10 times
 3. When was the last time you used it? (select one that applies)

Parachuting Task

Subject ID: _____
Date: _____

- a. Within last 30 days
- b. Within last 6 months
- c. Within the last year
- d. More than a year ago

4. Why did you use it? (*select all that applies*)
- a. Personal
 - b. Requirement

9. Have you ever parachuted in the past?

YES NO

a. If "YES":

- i. How many times? _____
- ii. When was the last time? _____

b. Was it:

- i. Personal/recreational
- ii. Requirement/service-related

10. Have you ever used a paraglider in the past?

YES NO

a. If "YES":

- i. How many times? _____
- ii. When was the last time? _____

APPENDIX F. DEMOGRAPHIC QUESTIONNAIRE



DEPARTMENT OF THE NAVY
NAVAL POSTGRADUATE SCHOOL
1 UNIVERSITY CIR
MONTEREY, CA 93943-5000

5000
00
14 Apr 23

From: President, Naval Postgraduate School
To: Dr. Amela Sadagic, CTV
Capt Jose Alfredo Vazquez Duran, FORNTL MX

Subj: PROOF OF CONCEPT VIRTUAL REALITY PARACHUTE TRAINING
SIMULATOR NPS.2023.0020-IR-EP6-7-A

Ref: (a) Chairman, Institutional Review Board, Naval Postgraduate School ltr of 11 Apr 23.

1. Per reference (a), the Naval Postgraduate School (NPS) Institutional Review Board (IRB) has determined your proposed research is consistent with applicable Department of Defense, Department of the Navy, and NPS Human Research Protection Program policies and regulations. I have reviewed the subject matter of this research and found it to be consistent with the NPS mission. Therefore, you are approved to begin conducting the research described in protocol found in enclosure (1) of reference (a).

2. You are required to complete a Research Protocol Check-in by 1 June 2023. Failure to complete the check-in could result in suspension or termination of your research.

3. You are required to report to the IRB any unanticipated problems or serious adverse events to the NPS IRB within 24 hours of the occurrence.

4. You are required to obtain consent according to the procedure approved in the IRB protocol.

5. Any proposed changes in IRB approved research must be reviewed and approved by the IRB prior to implementation except where necessary to eliminate apparent immediate hazards to research participants and subjects.

6. As the Principal Investigator(s) (PI), it is your responsibility to ensure the research and actions of all project personnel involved in conducting this study will conform with the IRB approved protocol and IRB requirements and policies.

7. At completion of the research, no later than expiration of approval, PI's will close the protocol by submitting a final report.

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Date: 2023.04.19 12:08:37 -0700

ANN E. RONDEAU, Ed.D
Vice Admiral, U.S. Navy (Ret.)

Copy to:
Chairman, NPS IRB

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