Extended reality (xR) flight simulators as an adjunct to traditional flight training methods.

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Abstract

Over the next 20 years, it is predicted that an additional 760,000 new pilots will be needed to meet the growing demands of the global aviation industry. With current training capability, this may be difficult to achieve. A potential means of improving the efficiency and lowering the cost of flight training is to use extended reality (xR) in place of traditional flight simulators and aircraft. Two studies are reported, each of which investigated the use of extended reality in flight training. First, a scoping review was conducted to synthesise existing studies. Second, two focus groups, involving 10 flight instructors, were conducted to gauge opinion toward the use of xR technology in flight training. Following synthesis and thematic analysis of the data sets, both studies revealed evidence that xR technology has the potential to be successfully employed in flight training, saving time and money, whilst also enabling increased training capability, although some potential limitations were identified. The interest in this technology, combined with evidence pointing to its potential usefulness in flight training suggests that further examination in this area by academia and industry is warranted.

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Glossary of Terms, Abbreviations, and Acronyms

BIP	Break in Presence
CAA	Civil Aviation Authority (New Zealand)
CASA	Civil Aviation Safety Authority (Australian)
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COTS	Commercial Off The Shelf
COVID-19	Coronavirus disease 2019
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FFS	Full Flight Simulator
FI	Flight Instructor
FTD	Flight Training Device
FTO	Flight Training Organisation
Haptic	The transmitting and understanding of information through touch
HMD	Head Mounted Display (used with xR technology)
ICAO	International Civil Aviation Organization
Immersion	Sensory immersion within a virtual environment
JBI	Joanna Briggs Institute
Legacy training equipment	FTDs, FFSs and aircraft
Pilot Licences	Certification for operating an aircraft - issued by the aviation authority of a country
MR (mR)	Mixed Reality
Presence	A sense of being in the virtual environment
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRISMA-ScR	PRISMA for Scoping Reviews
PTN	Pilot Training Next (USAF initiative)
Ratings	Flight crew qualification that authorises the holder to operate particular aircraft or exercise particular privileges.
USAF	United States Air Force
US Army	United States Army
US Navy	United States Navy
VE	Virtual Environment
VR	Virtual Reality
VRFS	Virtual Reality Flight Simulator
XR (xR)	Extended Reality

Chapter One: Introduction

1.1 Background to the Study

Despite the significant downturn in the global aviation industry due to COVID-19, the industry has experienced a faster than predicted resurgence in demand, with a potential predicted return to pre-pandemic requirement for air travel as early as 2022 (Aboulafia, 2020; Consulting.us, 2021; Hemmerdinger, 2021). Prior to the COVID-19 pandemic, the global aviation industry was experiencing sustained growth, whilst concurrently suffering from a significant shortage of qualified, experienced pilots (ICAO, n.d). According to the International Civil Aviation Organisation (ICAO), at least part of this shortfall was due to insufficient training capacity to meet demand, learning methodologies that had not evolved to meet the expectations of the next generation of learner, and the lack of accessibility to affordable flight training (ICAO, n.d).

Long-term traffic forecasts issued during the COVID-19 global pandemic by ICAO predict that passenger air traffic will, on average, increase annually by 4.2%, and by 3.5% for freight between now and 2035 (ICAO, 2018). As a result of the recovery and continued growth, aviation industry experts predict demand for an additional 260,000 to 350,000 new pilots over the next decade (ICAO, n.d; Leontidis, 2020). Based on a 20-year fleet forecast for commercial aircraft, aircraft utilization, attrition rates and regional crewing differences, this prediction equates to a total requirement of approximately 763,000 new pilots by 2039 (Boeing, 2020).

It takes approximately 24 months to train a multi-engine, instrument-rated commercial pilot (Careers.govt.nz, 2021). Due to more airlines requiring pilots to have a university degree

(Bureau of Labour Statistics, 2021), in addition to their licences, ratings and hour requirements[1], it can now take up to 48 months before a newly qualified pilot graduates flight training. It should be noted that newly qualified pilots, who only have the minimum hours required to hold a licence, may find it difficult to gain employment without first gaining experience. This is the Catch 22 of aviation, where a pilot needs experience (i.e., flight hours) to get a job, but without experience can not get a job (GCF Global, 2021).

Emerging technologies potentially offer a solution that could speed up training, reduce bottlenecks and increase the throughput of qualified pilots. By investigating the new teaching methods these technologies offer, flight training organisations (FTOs) could use them to supplement and assist the current approaches already in use.

1.2 Emerging Technology

Since approximately 2015, the extended reality (xR) industry, which incorporates the technologies of virtual reality (VR) and mixed reality (MR), has experienced rapid advances in growth (Statista, 2021) and capability (Statista, 2020). This in turn has led to increased interest in the technology by the aviation industry, in particular for its potential as a flight training solution (Markets & Markets, 2018). FTOs and air forces globally are evaluating these new technologies as a potential adjunct to their legacy training capabilities (e.g., aircraft, traditional flight training devices [FTD] or full flight simulators [FFS]).

[1] Hour requirements to qualify for licences and privileges vary depending on the state issuing the pilot licence. In NZ, a pilot must gain a minimum of 200 hours in order to hold a commercial pilot licence (CPL), and 1500 hours to hold an Airline Transport Pilot Licence (ATPL).

Traditional FTDs and FFSs, are typically expensive to purchase, ranging in price from several hundred thousand US dollars to over US$16 million when new, and in addition require specialist simulator staff and flight instructors to facilitate their operation (Frasca Flight Simulators, 2021; Government of Canada, 2020). Unlike FFSs, emerging technologies such as VR and MR based flight simulators, like those already in use by the USAF (Air Education and Training Command, 2020; Lewis & Livingston, 2018), could be considered more affordable, costing as little as US$1,000 (Ellis, 2019) per simulator. These VR flight simulators also do not require such specialist staff/instructors to operate them, and can offer students the opportunity to complete at least part of their training in a self-paced, learner-centric, collaborative environment, where autonomy and individualised training are encouraged (Pons, 2018).

Additionally, these technologies can enable realistic flight training to be conducted in a safe (i.e., minimal risk to the crew), high availability (i.e., fewer demands on staffing, or restriction due to maintenance issues or weather), less expensive (i.e., cheaper to purchase and operate than FTDs, FFSs and aircraft) and more environmentally conscious manner (i.e., reduced carbon footprint: fuel, oil etc.) (Masson, 2021). To enable decision-makers to make informed choices regarding technological advancement and future implementation, a better understanding of what xR is and how it can be used in the flight training environment is required.

1.3 What are xR, VR and MR?

Virtual reality (VR) is a combination of wearable computer hardware and specialist software that delivers immersive, high-fidelity, 3D content to the user via a head-mounted display (HMD) (i.e. goggles) that are worn over the eyes. Coupled with sophisticated specialist software, the HMD displays a simulated or virtual environment (VE), as they are known, that the user may interact with and manipulate in real-time. More simply put, by wearing a pair of hi-tech goggles over the eyes, VR allows a user to see, experience and manipulate a realistic representation of a computer-generated world. Mixed reality (MR) is similar in concept to VR in that the user still wears an HMD. The crucial difference between the two technologies is that in addition to the VE, parts of the physical world are also visible on screen, and can be selected and manipulated by the user. Together VR and MR are becoming more commonly referred to by the umbrella term *extended reality or xR* (Marr, 2019).

VR has existed in various forms since the 1960s. Due to the cost and the severe limitations of both the technology and computer processing power, it has only been used by those institutions with the significant financial resources to afford it (e.g., academia and the military). This situation began to change in 2014 when a small, newly formed technology company called Oculus VR was bought by Facebook for US$2 billion, prompting a huge increase in the level of interest in VR technology from Silicon Valley companies (Bailenson, 2018). As a result, industry experts now estimate that the attention, investment and innovation surrounding the xR industry will see growth rise from US$31 billion in 2021, to close to US$300 billion by 2024 (Alsop, 2021). A potential gauge of the raising level of interest in this technology is indicated by the number of large global technology hardware and software manufacturers that are entering the marketplace. Companies such as HTC (Vive Enterprise, 2019), Sony (Sony VR, 2021), Samsung (Samsung VR, 2021), Valve (Valve VR, 2021), Varjo (Varjo, 2021) and HP (HP, 2021) have all released xR associated hardware over the last six years. The interest and investment by firms such as these has led to rapid increases in innovation and advancements in the technology, with new generation HMDs being released regularly, each delivering an improvement on the last.

As a result of these developments, xR hardware in concert with faster and more powerful computers and software, can now represent myriad environments to a never-before-seen degree of realism (Hvass et al., 2017). Real-time selection and manipulation of virtual artefacts in a VE can be accomplished via commercial off the shelf (COTS) hardware (e.g., control sticks, steering wheels, foot pedals, levers and switches) like those manufactured by Swiss company Brunner Elektronik AG (Brunner, 2021) and Saitek (Saitek, 2021). While sensation feedback through the skin, called *haptics* (Science Direct, 2021), can be achieved via worn *garment* type devices, (e.g., gloves and other clothing) like Haptx gloves (Haptx, 2021). Advancements in hand gesture recognition technology are also currently taking place (Bubniuk, 2020; UltraLeap, 2021), although gesturing cannot provide nuanced touch-like feedback sensation without additional physical hardware. Coupled with the capability to deliver extraordinary levels of physical operation/interaction, xR systems now have the ability to deliver high-fidelity, real-time, total immersion training experiences (Cooper et al., 2021; Korteling et al., 2017).

1.4 Conventional Flight Simulation

Simulators have played an integral role in the training of aviators at all levels for over one hundred years. Since the 1920s, organisations responsible for flight training have used simulator technology to reduce costs, extend aircraft life, maintain flying proficiency, and provide more effective training (Taylor et al., 2003). Flight simulators have advanced a great deal since Edwin Link invented the Link Trainer in 1929 (Jeon, 2015). From these humble beginnings, which used wooden frames and pneumatic bellows, the modern full-flight simulators (FFS) commonly used by airlines and FTOs today incorporates six-axis moving platforms, highly complex systems and require specialist staff to maintain and operate them (CAE, 2021) (see Figure 1). As FFSs include all of the systems necessary to realistically represent an aircraft's functionality, it is now possible to train and qualify pilots on *type* (i.e., aircraft model type—Boeing 777) without the need for them to fly the real aircraft (Flight Training Alliance, 2019). Interest in FFSs is increasing with growth in the flight simulator market expected to reach US$7.7 Billion by 2025, representing a compound annual growth rate (CAGR) of 5.2%, from 2019 (Markets & Markets, 2019). At an approximate cost of between $6 and $16 million US dollars each (Government of Canada, 2020), FFS are beyond the economic reach of all but the largest FTOs, and even many airlines.

Figure 1

An example of the outside and inside (flight deck) of a Boeing 777 Full Flight Simulator (FFS) operated by training provider Flight Safety International.

Flight training devices (FTDs) are an alternative to FFSs. Typically they are less expensive (i.e., hundreds of thousands of dollars rather than millions) and less complex (i.e. usually fixed base as opposed to full-motion) to operate (Frasca Flight Simulators, 2021). FTDs can provide pilots with the realistic feel, function and sound associated with an actual aircraft, although they still require specialist technical support, which is often carried out by the manufacturer or an agent as part of a service contract (Frasca Flight Simulators, 2021; L3 Harris, 2021)

1.5 XR Simulation

With the popularisation of the home computer in the 1980s, the complex world of flight simulation was made more generally available (Bonner, 2021). The first PC based flight simulator was written in 1975, although it wasn't until the 1980s that US software company subLOGIC released the first version of a home flight simulator for the Apple II which featured just four colours on a monochrome display (Bonner, 2021). As PCs became more powerful, flight simulation software evolved and become more sophisticated. Now applications such as Laminar Research's X-Plane (X-Plane, 2021), Lockheed Martin's Prepar3D (Prepar3D, 2021) and Microsoft's Flight Simulator 2020 (Microsoft, 2021) are leading the way in the consumer flight simulator marketplace, each developing software that delivers texture, graphics and scenery at unparalleled levels of quality and realism. In addition to the simulator software, there now exists a plethora of COTS flight simulator hardware manufacturers supplying control sticks (i.e., joysticks), rudder pedals, throttle quadrant (i.e., power/speed controllers) and a seemingly unending array of associated peripherals (Logitech, 2021; Saitek, 2021; Virpil, 2021). The ability of consumer-grade technology and home flight simulator systems are still very limited when compared to the quality and realism provided by FSSs and FTDs. One or two monitors, a keyboard, joystick and possibly a throttle quadrant, falls significantly short of providing the immersion and functionality required for professional flight training.

Due to the technological advancements in modern computing power, xR technology-based flight training is bridging the gap between professional FFSs/FTDs and the consumer PC flight simulator. As a result, xR simulators may now be able to offer a viable addition to the methods conventionally employed by FTOs and deliver high-value, realistic and cost-effective flight training (Pope, 2019). The United States Air Force (USAF), for example, are already taking advantage of simple Virtual Reality Flight Simulators (VRFSs), comprising an HMD, control stick, throttle, rudder pedals, monitors and a stationary seat (Lewis & Livingston, 2018). These VRFSs, although basic in appearance, are reducing the number of expensive, time-consuming flights that students require in real training aircraft (Lewis & Livingston, 2018; Pope, 2019). Several studies have suggested that virtual reality training improved productivity and flight experience, especially in areas of critical factor recognition, decision-making skills, situational awareness, and crew coordination (Buttussi & Luca, 2015; Laptaned et al., 2019; Pope, 2019; Wilson et al., 2020). Unlike FFSs and FTDs, xR technology, (i.e., VRFSs) is relatively inexpensive and can quickly and easily be reconfigured in terms of hardware and software changes to represent different aircraft without the need to own or operate additional physical simulators. The versatility of VRFSs then can potentially offer FTOs the unique ability to fly any of their aircraft, in any environmental conditions, anywhere in the world, at any time.

1.6 Other industry xR applications

In an era of stringent occupational health and safety legislation, it is becoming increasingly difficult to manage the risk involved in training personnel involved in high consequence activities, whilst also maintaining organisational peak performance (Training Industry, 2021; Wentworth, 2018). By using lower risk, lower consequence virtual environments, VR may enable industry to train using new, improved and safer methods that would previously have been too difficult or too dangerous to consider (Forbes, 2020). Effective training often requires individuals or teams to undertake realistic, vocationally relevant scenario-based training exercises (Cox, 2010; Forbes, 2020). The improvements in VR technology has led to growing interest among high-consequence industries (Wentworth, 2018), in many instances within industries not usually considered traditional users of computer simulators (Wentworth, 2018).

Learning is a holistic process of adaptation and not just cognition, which involves a learning cycle of thinking, feeling, perceiving and behaving (Kolb & Kolb, 2011). VR enables industries to conduct realistic training that supports this learning method in safe controlled environments with no consequences for failure (Wentworth, 2018). Firefighters are now able to train to fight fires, such as large bush fires or structures, in virtual reality environments, which, prior to VR would have been impractical or too dangerous (Nahavandi et al., 2019). Athletes are using VR to conduct immersive performance-based analysis, enabling them to improve coordination and decision making (Bailenson, 2018) and surgeons have been given the opportunity to practice procedures and hone their skills countless times without endangering life (Aggarwal et al., 2006; Ganni et al., 2020). Haptic hardware devices such as firefighting hose branch equipment (FLAIM, 2021) and surgical implements (Twinn, 2019) are further adding to the realism of the VR learning/training process. Physical feedback, where used, enables professionals to practice and train in a more realistic but safe, controlled and repeatable environment (Barnard, 2019a).

1.7 Time and Cost Considerations

Griffin and Murrie (2019) found that financial factors were of significant influence in both the ability of student pilots to undertake flight training, as well as the industry's ability to retain newly qualified pilots. By implementing xR technology in the form of VRFSs, time and cost reductions could be made by substituting actual aircraft flying hours with simulator training (Masson, 2021; Pope, 2019), potentially making flight training more accessible and affordable. VRFSs may also have the ability to reduce the scale of operations, specifically in areas such as airport and airways charges, maintenance provision and the quantity of fuel (and other carbon-based materials) consumed, thus simultaneously lowing costs and the negative environmental impact of aviation training (Lawrynczyk, 2018; Pennington et al., 2019; Pope, 2019; Trinon, 2019). These latter potential advantages would also bring operators in line with environmental initiatives such as ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (ICAO, 2021).

Better use of training time allocations, fewer delays or cancellations due to weather, or unavailability of aircraft due to maintenance issues, results in less time required to train pilots. A reduction in airframe hours and fuel usage, less maintenance, and a marked reduction in the associated ancillary logistic costs might also lead to additional financial savings. A recent cost-benefit analysis conducted by Pope (2019) found that the US Air Force (USAF) alone could make savings of tens of billions of US dollars to fixed and variable operating costs, whilst also increasing throughput along the training pipeline, over the next decade by implementing xR flight training in the form of the Pilot Training Next (PTN) initiative. It is suggested then, that in the civil sector, potential operational savings such as these could be passed on to the consumer in the form of reduced training fees. This in turn could increase the attractiveness of a career in aviation to a broader base of potential student pilots to whom at present the cost of flight training is prohibitively high (Ahluwalia, 2017; Robinson, 2021).

VR training also has the ability to be customised to meet the optimum rate of learning and the ability of an individual, again with the potential to save time and money (Chen, 2016). Furthermore, training scenarios can be run and re-run countless times, within which, it is possible to change only one or two variables and observe any new effects, consequences and/or changes in performance (Lozano et al., 2020). As xR flight training technology is less dependent upon factors such as aircraft/simulator instructor availability, the weather, maintenance issues or other support/logistical limitations, their adoption could result in fewer delays and have a positive effect on the timely throughput of student pilots along the training pipeline (Pope, 2019).

1.8 Looking Forward

The next generation of aviators—Generation Z, or those born from 1997 onward (Dimock, 2019)—have engaged with digital multi-media and active, experiential, learning technology from birth (Panopto, 2020). In order to fully engage with this generation of learner, FTOs will have to strongly consider the implementation of more modern and engaging methods of delivering training (Panopto, 2020). XR is still an emerging technology and is, as a result, still a relatively new concept to the aviation industry. That said, as already mentioned, xR is currently having a significant impact on the way a growing number of professionals gain and maintain their skills and proficiency (Biggs et al., 2018; Cooper et al., 2021; Lewis & Livingston, 2018; Likens & Eckert, 2021; Pons, 2018). Furthermore, studies have suggested that individuals who have undertaken xR training demonstrate faster learning and increased knowledge retention, over those using standard training methods (Babu et al., 2018; Krokos et al., 2019). Air Forces globally, including the Royal Air Force (RAF), United States Air Force (USAF) and Royal Australian Air Force (RAAF), are already using xR pilot training to various degrees and with encouraging results (Pope, 2019). The USAF implementation of this technology, called Pilot Training Next (PTN), is a programme aimed at investigating the viability of xR technology to train the next generation of pilots, as well as address the current pilot shortage being experienced by the organisation (Air Education and Training Command, 2020; Lewis & Livingston, 2018; Pennington et al., 2019). It could, therefore, be hypothesised that pilots and civil FTOs might also benefit from employing these newer methods of training in this increasingly technological era, as such, it is suggested that xR flight training technology is worthy of further consideration.

1.9 Aim and conduct of the Thesis

Based on the literature review, the following overarching research question (RQ) was derived:

(RQ1) *What is the nature of the evidence to support the use of extended reality (xR) flight simulators in traditional flight training methods?*

To enable the RQ to be answered as fully as possible a Scoping Review (ScR) study was conducted to facilitate the collection of a broad range of data for subsequent analysis. The objective of the ScR was to 1) identify all relevant literature to assist in answering the RQ, and 2) ascertain if enough evidence existed to warrant the conducting of a full systematic review of the literature at a later date.

The ScR method of systematic review was chosen because they are commonly employed to address broader research questions and assist in mapping key concepts that underpin a particular field of research (Arksey & O'Malley, 2005). ScRs are also used to identify and clarify working definitions, and/or the theoretical boundaries of a specific topic (Arksey & O'Malley, 2005; Pham et al., 2014). For these reasons, it is suggested that as the subject of the research being conducted was relatively new, and specialised in nature, that choosing the ScR method of evidence synthesis was most appropriate.

During the initial ScR data identification phase, it was quickly noted that few studies existed that were relevant to RQ1, and even fewer pertained to civil flight training involving civilian student pilots and/or flight instructors. As a result of this, and to enable RQ1 to be answered as fully as possible, a Focus Group (FG) study was designed and conducted that would gather data from a small group of civilian flight instructors.

The decision to conduct an FG study was justified as being most relevant in this instance as they are particularly well suited to the inductive[2] style of research being undertaken (Dudovskiy, n.d.). This is because FG results enable the generation of broad meanings, and the establishment of patterns and relationships from the data set (Dudovskiy, n.d.). FG researchers systematically analyse media, such as audio recordings and transcripts, which are then thematically coded to determine the presence (or lack) of patterns, meanings, processes and norms (Bloor et al., 2011). FGs then are a useful tool that can be used to provide a valuable means of documenting the complexities through which group norms and meanings are shaped, elaborated upon and applied in a real-world context (Bloor et al., 2011).

The objective of the FG study in this thesis was to gather data from ten civilian flight instructors (FIs) currently employed at New Zealand's largest FTO with the intent of answering an additional research question—RQ2:

> (RQ2) *What are the opinions of professional civilian flight instructors toward using virtual reality flight simulators as an adjunct to traditional flight training methods?*

1.10 Outline of the Thesis

For the reasons previously detailed, both an ScR and FG approach was chosen to conduct this study. Primarily this was due to the inductive nature of the two methods, which aligned well

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[2] The antithesis of inductive is the deductive method. Deductive research therefore begins with a known theory or phenomenon and leads to the generation of a new hypothesis. The hypothesis is then tested through observations that either confirm or a reject it.

with the exploratory nature of the work. Together, it could be suggested, they can provide a richer insight into the problem.

The completed studies are presented below in a format that closely resembles that seen in manuscripts that might be submitted to an academic journal. As such this masterate research thesis is presented as one might expect a PhD by publication to be presented.

The ScR is presented in Chapter Two, where details of the breadth and scope of the existing studies are extrapolated, analysed, summarised and discussed. In Chapter Three, the resultant thematic data from the two FGs are presented with the intent to provide some insight into the pros and cons of VRFSs, as perceived by the civilian FIs who took part.

Both studies combined are discussed and concluded in Chapter Four, this chapter is intended to assist decision-makers in informing policy regarding the adoption of VRFS simulators as an adjunct to existing flight training solutions, and to guide academics in future research initiatives.

Chapter Two: Scoping Review

2.1 Introduction

2.1.1 Reason for Conducting a Scoping Review (ScR)

When considering aviation's past and current adoption of technology to train pilots, (i.e., simulators), it could be suggested that VRFSs have the potential to deliver a new era of aviation training capability. Anecdotally, xR use by FTOs so far appears very limited, as does an understanding of the technology's capabilities and benefits in the context of aviation training. Establishing a better understanding of the depth and breadth of the existing knowledge on the topic was therefore required.

2.1.2 Scoping Reviews

The following sections will introduce the ScR as a research method, explain how they are different from some other review syles, and detail under what circumstances they might be conducted.

When initially setting out to gather evidence to assist in answering a research question, researchers may encounter difficulties in identifying information that is relevant. In addition to this, they must establish if whatever literature has been discovered is of good quality and has been compiled objectively using the appropriate scientific process and rigour (Goldstein & Goldstein, 1978). When searching for literature, not all researchers adopt the same high standards to ensure the quality of the selected research or protect against the introduction of biases (Arksey & O'Malley, 2005). To help defend against these occurrences, a systematic, replicable, and extensive search of the international literature is required (Peters et al., 2015).

One such method commonly employed to achieve this objective is to undertake a systematic review of the literature (e.g., a scoping review) (Arksey & O'Malley, 2005).

With an increase in the accessibility of primary research through means such as Google Scholar, Scopus and Web of Science etc., the conducting of scientific reviews as a research method has increased (JBI Manual for evidence synthesis, 2020; Peters et al., 2015). ScRs, also known as "mapping reviews" and "scoping studies" are just one of many different types of literature review methods available to researchers (Grant & Booth, 2009; JBI, 2020). Arksey and O'Malley (2005) proposed the original framework for conducting ScRs in 2005 and stated that "scoping reviews have great utility for synthesizing research evidence and are often used to map existing literature in a given field in terms of its nature, features, and volume". Following on from the work of Arksey and O'Malley, the Joanna Briggs Institute (JBI) later developed and refined further guidelines for the conducting of ScRs (JBI, 2020), and in 2018 the Preferred Reporting Items for Systematic Reviews Statement (PRISMA) was extended by a number of experts in scoping reviews and evidence synthesis, to include Scoping Reviews (Tricco et al., 2018). It is this model, the PRISMA-ScR (Tricco et al., 2018), that was adopted to guide the design of the current study.

Systematic reviews, such as ScRs, stress the need for the same degree of thoroughness and accuracy of method that is expected of any primary research (Gough et al., 2013). Goldacre (2012) stated that:

> "When conducting systematic reviews, instead of just mooching through the research literature, consciously or unconsciously picking out papers here and there that support [our] pre-existing beliefs, [we] take a scientific,

> systematic approach to the very process of looking for scientific evidence, ensuring that [our] evidence is as complete and representative as possible of all the research that has ever been done"
> (p.174–176)

Traditionally, systematic reviews aim to answer a specific question/s as set out by restrictive a-priori factors that are detailed in the protocol (Peters et al., 2015). An ScR, by contrast, uses a broader approach, generally with the intention of plotting the literature and addressing a wider research question (Peters et al., 2015). ScRs lend themselves well to the exploration of emerging evidence when it might still be unclear what actual evidence exists, and what specific questions can be asked (Munn et al., 2018). Thus, they are commonly used for 'reconnaissance', to clarify working definitions and conceptual boundaries of a topic or field. The three most common reasons for carrying out an ScR are: 1) to explore the breadth and depth of the current literature, 2) chart and summarize the evidence, and 3) inform potential future research efforts (Tricco et al., 2016a). As this thesis was focused on the use of a relatively new technology that was being used in a specialised area within a single industry, it was unclear at the outset what evidence, if any, might exist, as such the ScR method appeared to be a good fit for the aim of the study.

2.1.3 Uses of Scoping Reviews: Strengths and Challenges of the method

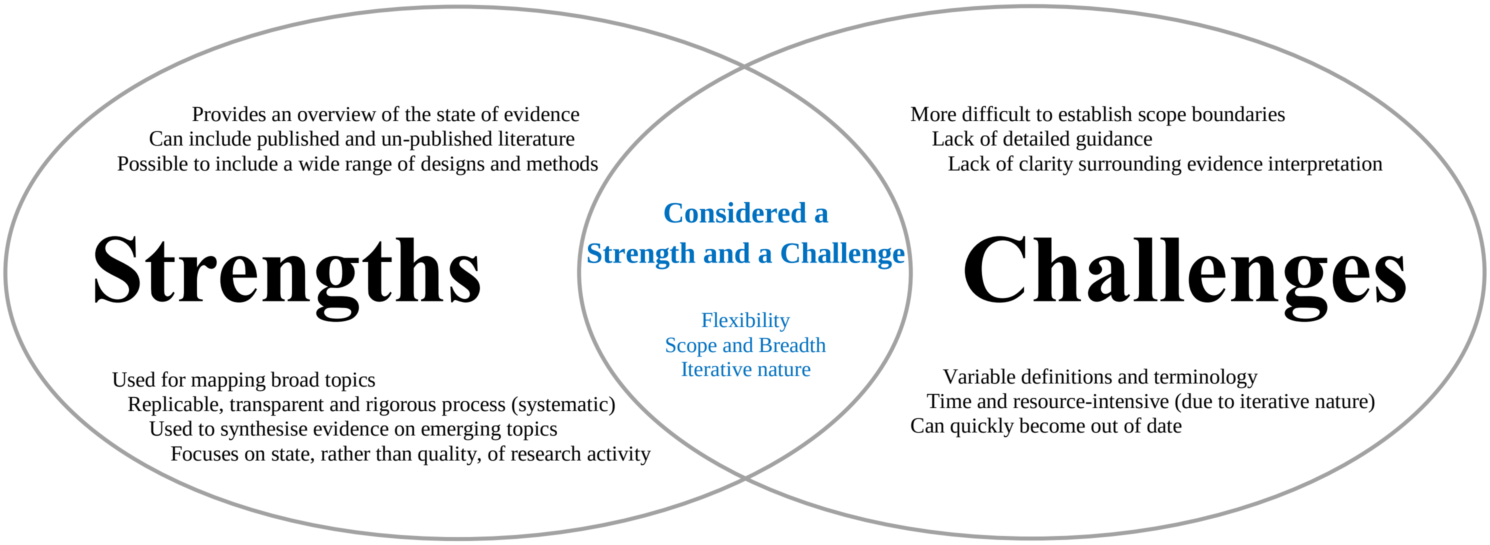
Pham et al. (2014) suggest that the strengths associated with ScRs included: their flexibility, the ability to include both published and unpublished (grey) literature, the option to include studies with a wide range of study designs and methodologies, and that it is possible to include qualitative and quantitative synthesis approaches. Pham et al. (2014) also reported that the systematic process (i.e., replicable, transparent, rigorous) affords the opportunity to explore and gather evidence on newly emerging topics (i.e., areas with little published evidence) because the approach is not as rigid as traditional systematic reviews. ScRs also focus on the state, as opposed to concentrating on evaluating the quality, of research activities, this, in turn, provides the opportunity for policy makers to make decisions based on the evidence (Pham et al., 2014) (see Figure 2).

Although the flexibility and iterative nature of ScRs might be considered positive, Pham et al (2014) suggested that the need to define (and redefine) the research question, search strategy and selection criteria increased the time required, and often the resources necessary, to complete the review. The broad scope and sometimes lack of clarity regarding the boundaries of the review means that ScRs are often time-consuming and take much longer than originally planned, which, potentially, could result in a study becoming quickly out of date (Pham et al., 2014). The lack of detailed steps, guidance, standards and method has been identified as an issue with ScR, with the need for more clarification in these areas (Pham et al., 2014). Regarding this last observation, it could be argued that since this study, the work carried out by PRISMA-ScR and JBI to design a common framework may have potentially reduced these issues (JBI, 2020; Peters et al., 2020; Tricco et al., 2018). Finally, reporting the results of an ScR may also be problematic, with difficulties publishing reviews specifically of this type in academic journals, often due to word count (Pham et al., 2014) (see Figure 2).

It should be noted that some of the challenges mentioned that are associated with the conduction of ScRs can also be considered strengths. These areas of crossover included the flexible nature of ScRs, the breadth and broad scope of the topic under review and the iterative process that can be applied to the review process (Pham et al., 2014) (see Figure 2).

Figure 2

The Strengths and Challenges of Scoping Reviews, adapted from Pham et al. (2014)



2.1.4 Summary and Justification

As suggested, ScRs are undertaken to provide an initial map of the currently available body of evidence (Anderson et al., 2008): evidence that has not yet been comprehensively reviewed, or displays a large, varied, or complex nature and/or is not open to a more precise method of systematic review (Peters et al., 2015). ScRs may be undertaken to determine whether or not a full systematic review should be completed, or, they may be carried out independently as an exercise in and of themselves in order to summarise and disseminate research findings and/or identify research gaps (Anderson et al., 2008; Arksey & O'Malley, 2005). It is for these reasons that an ScR was adopted as the method to systematically map and synthesise the research data already carried in this area, as well as to identify any existing gaps in the knowledge (Tricco et al., 2018).

2.1.5 Conduct and Intent of the Scoping Review

A search for previous reviews, of any type (e.g., scoping, systematic, narrative, or rapid), was conducted in early January 2021 and none were found. Further searches using academic databases and academic search engines (detailed in the Method section) subsequently returned limited studies in the area of interest. Therefore, in line with suggestions made by Arksey and O'Malley (2005), and Levac, Colquhoun and O'Brien (2010), it was decided that the ScR should be conducted to fulfil the following intent:

- Answer the research question(s) (as detailed in Chapter One) through the investigation of the extent, range and nature of any existing research activities and literature.
- Provide an overview of the topic and disseminate any research findings to relevant or interested parties (e.g., FTOs, aviation authorities and flight simulator technologists).
- Determine the value of conducting a full systematic review.
- Identify and guide areas for potential future research efforts.

2.1.6 Ethics Approval

Prior to commencement, a discussion took place between the researcher and the research's supervisor. The ethical considerations surrounding this particular type of research project were discussed and considered. It was concluded that human ethics approval was not required for this ScR study as it solely involved the analysis of secondary data, openly available in the public domain, and therefore fell outside of the scope of the institutional human ethics committee.

2.2 Method

2.2.1 Eligibility Criteria

Peer-reviewed journal articles, conference proceedings, reports and unpublished grey literature that were published in English only, between January 2015 and January 2021 were considered for inclusion. The rationale for this date limitation was with the intent to only include studies conducted since the beginning of the third wave of VR (Heim, 2017), which was experienced in the wake of Facebook's acquisition of Oculus in 2014 (Barnard, 2019b; Global Data, 2019; Knight Foundation, 2016; Moltenbrey, 2016). Limiting the date range of the ScR to this period raised the likelihood that only studies using new generation hardware and software would be included. As this ScR forms part of a master's thesis, there was no funding available for translation services, hence, only studies published in English were considered for inclusion. Any empirical study, whether quantitative, qualitative or mixed-methods were included in order to consider the broadest range of evidence, measurements and approaches. Papers were excluded if no details of participant numbers were included in the study. This is due to the potential for bias or extreme results to be introduced and it could be suggested that the omission of these details is indicative of low-quality research, or an attempt to inflate the significance of the results (Dermatol, 2014). Additionally, studies were not included if they discussed aviation or flight training but xR was not employed in any way, or if there was no aviation or flight training context or application at all. Similarly, opinion pieces or review articles were also excluded from the final study selection. As only one reviewer was conducting the screening of studies, there were no disputes or disagreements to resolve. This is acknowledged as a limitation.

2.2.2 Selection of Sources of Evidence

Inclusion criteria were based on the population, concept, context (PCC) protocol advised by the Joanna Briggs Institute (JBI) Reviewer's Manual, Chapter 11: Scoping reviews (Peters et al., 2020).

Inclusion criteria:

- **Population:** Pilot of an aircraft (qualified or unqualified): fixed, rotary-wing, or UAV.
- **Concept:** Employs xR (VR or MR) flight simulation technology.
- **Context:** Aeroplane/helicopter/UAV industry flight training or education.
- **Language:** Published in English.

Exclusion criteria:

- **Population:** Did not involve pilots of an aircraft (qualified or unqualified): fixed, rotary-wing, or UAV.
- **Concept:** Use of traditional simulation/simulators without the employment of xR technology.
- **Context:** Did not involve aeroplane/helicopter/UAV industry flight training or education.
- **Language:** Was not published in English (financial restriction).

2.2.3 Information Sources and Search Strategy

To identify relevant material for the ScR the academic databases: Web of Science (WoS) and Scopus, and the academic search engine Google Scholar (GS), were searched in January 2021. The following Boolean search strings were submitted to each of the databases mentioned above.

- "flight sim*" AND "virtual reality" OR "mixed reality" OR "extended reality"
- "flight training" AND "virtual reality" OR "mixed reality" OR "extended reality"
- "pilot training" AND "virtual reality" OR "mixed reality" OR "extended reality"

- "aviation training" AND "virtual reality" OR "mixed reality" OR "extended reality"

After being designed the search strategies were independently verified for technical correctness and soundness by an experienced university reference librarian.

Two preliminary screening steps were taken. For GS only, due to the number of results returned, and as recommended in previous studies (Badampudi et al., 2015, 2016; Krishnaratne et al., 2020), only the first 15 pages of returns (10 returns per page, 150 total results) were considered for inclusion. Following this, a title only screening was carried out on all results returned from all sources, to identify returns that were not relevant.

On completion of these preliminary screening steps, all of the studies of interest were uploaded to CADIMA (CADIMA, 2021; Kohl et al., 2018). CADIMA is a web-based tool used for the facilitation, conduct and document assurance of systematic reviews, systematic maps and literature reviews. CADIMA was then used to conduct title-and-abstract, and full-text screening before the final studies of interest were exported and uploaded to Endnote for storage and referencing.

Duplicates were identified and removed during the CADIMA import process with a further check for duplicates being conducted after the final import to Endnote. Due to time and financial constraints no searches of printed databases by hand were conducted, although a manual search of the reference lists of the included studies was carried out. Requests for publicly unavailable studies were made directly to the author/s, and a public request for any relevant new or unpublished studies was made on Research Gate and LinkedIn.

This ScR was conducted in partial fulfilment of a master's degree following Massey University protocols. These rules stipulate that research projects must be conducted solely by an individual, as such all screening was carried out in isolation with no external input, and this is acknowledged as a limitation.

2.2.4 Data Extraction Process

During the full-text review, a data extraction table that was developed following the suggestions made in the JBI Reviewer's Manual (JBI Manual for evidence synthesis, 2020; Peters et al., 2020) was completed. Relevant data, relating to: author(s), year of publication, title, publication source, country of origin, aims/purpose, population, method, concept, conclusions and key findings, was included. The data extraction table containing the results of this process can be seen in Table 1 and Table 2 of the results section. As far as possible, ScR best practice was adhered to, this guided the final design of the data extraction table and which data was or was not included from the selected studies (Peters et al., 2020).

2.3 Results

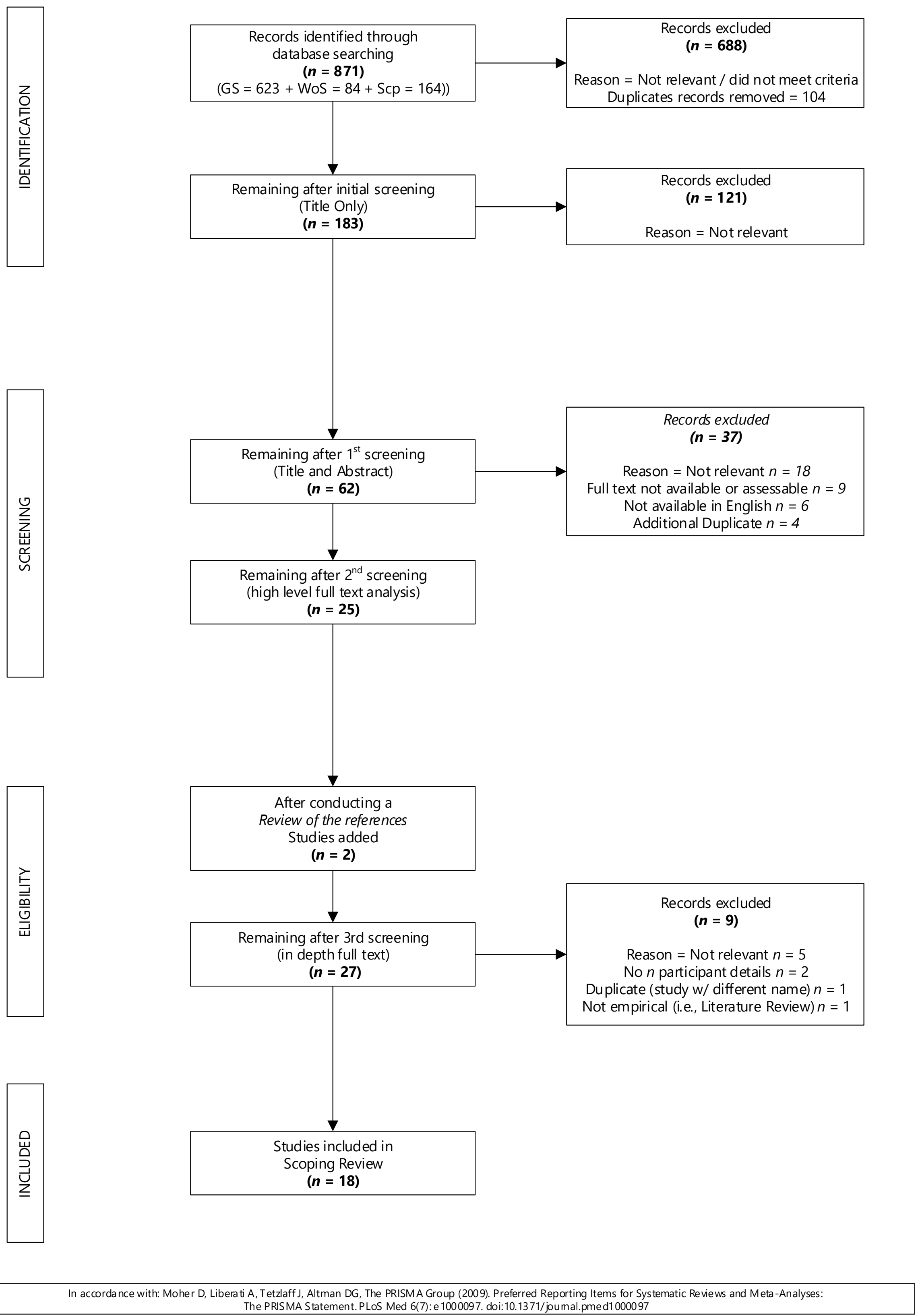
2.3.1 Selection of Sources of Evidence

The database searches detailed above returned a total of *n* = 871 potential studies of interest. After an initial title only screening and the removal of *n* =104 duplicates, a further *n* = 584 studies were omitted as they were not relevant. The remaining *n* = 183 studies underwent title and abstract screening, after which a further *n* = 121 studies were excluded as being not relevant, leaving *n* = 62 studies identified as of potential or probable interest. On completion of a high-level full-text screen, a further *n* = 37 studies were discounted for reasons such as the study was not relevant, the full text was not accessible, it was not available in English, or was a duplicate. Following the high-level screening, *n* = 25 studies remained. At this point, two studies were identified and added following a review of the references, meaning *n* = 27 studies were subjected to the final in-depth full-text screening. During this final stage, a further *n* = 9 studies were excluded because they were either not relevant, it was discovered they were duplicate studies published using a different title or were not empirical. The *n* = 18 remaining studies were selected for inclusion in the ScR. No additional studies were acquired as a result of the personal or public requests made to authors, Research Gate or LinkedIn.

The flow diagram (see Figure 3) illustrates the stages of the literature search and details the number of studies screened at each stage, including the number of those studies included/excluded.

Figure 3

Literature Search Stages: Detailing numbers of sources of evidence screened and included in the review, with reasons for exclusions at each stage.



2.3.2 Characteristics of Individual Studies

Analysis of the characteristics of individual studies provided the following data. Conference proceedings accounted for *n* = 8 (44%) of the included studies with only *n* = 2 (11%) published in peer-reviewed journal articles. All *n* = 18 of the studies were published since 2018. Of the included studies, *n* = 11 (61%) of the lead authors were based in the USA, *n* = 3 (17%) in Canada, *n* = 1 (5.5%) in Belgium, *n* = 1 (5.5%) in Germany, *n* = 1 (5.5%) in Poland and *n* = 1 (5.5%) in Sweden. The selected studies employed a combination of quantitative, qualitative, or mixed-methods. In total *n* = 13 (72%) of the studies used quantitative methods: *n* = 7 (54%) quasi-experimental; *n* = 3 (23%) correlational; *n* = 2 (23%) descriptive and *n* = 1 (8%) experimental. Ten of the studies used qualitative methods to gather results, with *n* = 7 (70%) using questionnaires; *n* = 2 (20%) observations; *n* = 1 (10%) interviews.

The majority of the included studies, *n* = 11 (61%), were focused on civilian flight training, with the remaining *n* = 7 (39%) focusing on military flight training. Conversely, of the total participants, *n* = 1,099 (76%) were military, which significantly outweighed the *n* = 339 (24%) of civilian participants reported. Of the *n* = 1,438 participants in the included studies, *n* = 205 (14%) were qualified pilots who held a cross-section of licences from PPL to ATPL (or the military equivalent); *n* = 1048 (73%) were student pilots undergoing formal flight training; and *n* = 185 (13%) were unqualified non-pilot participants under instruction.

A summary of the conclusions and key findings of the studies suggested that *n* = 2 studies (*n* = 1 descriptive and *n* = 1 observational) explicitly reported xR could offer some degree of cost savings in pilot training and *n* = 4 (*n* = 2 observational and *n* = 2 descriptive) stated pilot training time could potentially be reduced. Thirteen studies (*n* = 4 quasi-experimental; *n* = 3 qualitative questionnaire; *n* = 2 observational; *n* = 2 descriptive; *n* = 1 correlational and *n* = 1 experimental) reported positive learning experiences, and $n = 5$ ($n = 2$ correlational; $n = 1$ observational; $n = 1$ quasi-experimental and $n = 1$ descriptive) stated that xR was potentially as good as legacy methods. Although xR could potentially reduce the actual number of flying hours required, it should be remembered that there will be a finite limit to this number as flying a real aircraft is, presently, still a regulatory requirement to gain a pilot licence. In the future, aviation governing authorities may amend this, and reduce the number of flight hours required.

Some form of negative training experience (i.e., functionality issue, simulator sickness) was reported in $n = 2$ quasi-experimental studies, while $n = 3$ quasi-experimental studies did not support the idea that xR flight training was better than the alternative legacy option. Distraction, stress and high cognitive load whilst in xR were reported in $n = 3$ ($n = 2$ quasi-experimental and $n = 1$ qualitative questionnaire) studies—although this might not necessarily be considered a negative outcome—with distraction mitigation and desensitisation being options to counter this.

Information regarding each of the studies that were included can be found in Table 1 & Table 2. Table 1 provides an overview of the study, including, author, year, title, publication venue, the aim of the study and details of the population. Table 2 details the methods used, the conclusions or outcomes and the key findings that relate to the research question.

Table 1

Data Extraction Table: Publication details

Author/s (Base)	Year Pub.	Title	Pub. Type	Aims/purpose	Population / Sample size
Pope, T (USA)	2019	A cost-benefit analysis of Pilot Training Next	Department of Operational Sciences, Graduate School of Engineering and Management, Wright-Patterson Air Force Base	To compare legacy undergraduate pilot training (UTP) costs, production, and quality to the recently initiated Pilot Training-Next (PTN) VR program through a cost-benefit analysis of Cost, Production and Quality	USAF student pilots (cost-benefit analysis - no numerical data for *n* of participants)
Sheets, T; Elmore, M (USA)	2018	Abstract to action: Targeted learning system theory applied to adaptive flight training	Air Command and Staff College, Air University, Maxwell Air Force Base	The study takes a practitioner's approach to transform abstract ideas into actionable options for the future of education and training. Using exploratory and applied design research, the study draws on the scientific knowledge and uses technologies to create the idea of the Targeted Learning Systems Theory (TLST) using Virtual Reality Learning Environments (VRLE)	A convenience sample of 40 USAF participants with various levels of flight experience
Sakib, M; Chaspari, T; Ahn, C; Behzadan, A (USA)	2020	An experimental study of wearable technology and immersive virtual reality for drone operator training	27th International Workshop on Intelligent Computing in Engineering	To analyse drone operator's physiological data (collected by wearable devices) to enable an objective comparison of how VR training resembles real-world situations	25 participants aged 25-30 19 males 6 females
Dalladaku, Y; Kelley, J; Lacey, B; Mitchiner, J; Welsh, B; Beigh, M (USA)	2020	Assessing the effectiveness of virtual reality in the training of army aviators	2020 Annual General Donald R Keith Memorial Capstone Conference - Society for Industrial and Systems Engineering	To modernize flight training the US Army introduced Virtual Reality (VR) through the Aviator Training Next (ATN) program. This program uses VR to supplement "traditional hands-on" training. ATN's primary goal is to produce aviators of the same quality as those trained via traditional means without adding time	Historic data from 5 traditional flight school classes All ATN classes over 6 months with a subset of 10-15 students from each class randomly selected for participation
Wilson, J; Scielzo, S; Nair, S; Larson, E (USA)	2020	Automatic gaze classification for aviators: Using multi-task convolutional networks as a proxy for flight instructor observation	International Journal of Aviation, Aeronautics, and Aerospace, Embry-Riddle Aeronautical University – Worldwide	Can using eye-tracking (with machine learning) objectively assess aviator scan patterns during training, and thus reduce instructor overall workload Two key research questions: 1. Do flight instructors assess the quality of scan patterns of an aviator similarly? 2. If so, can machine learning techniques be used to automate the instructor evaluation of scan pattern quality for aviators in various phases of flight?	40 participants: 21 pilots (all with military flying experience), 9 operators (with some flight or simulation experience), and 10 novices (no aircraft experience at all)

Author/s (Base)	Year Pub.	Title	Pub.Type	Aims/purpose	Population / Sample size
McGowin, G; Xi, Z; Newton, O; Sukthankar, G; Fiore, S; Oden, K (USA)	2020	Examining enhanced learning diagnostics in virtual reality flight trainers	Proceedings of the Human Factors and Ergonomics Society Annual Meeting	Summarize findings from learning and training research that can be adapted to virtual reality to better understand the relationship between learning and transfer Describe where these methods were integrated to study learning and training using a blend of traditional media with virtual reality simulation assessments	23 undergraduate students, 15 male and 8 female 20 participants had little to no familiarity with flight simulators 18 participants rated their video game expertise as fair or less
Ommerli, C (Canada)	2020	Examining the effects of perceived telepresence, interactivity, and immersion on pilot situation awareness during a virtual reality flight exercise	Faculty of Graduate and Postdoctoral Affairs, Carleton University	The primary objective of the research was to validate and quantify the effects of telepresence, interactivity, and immersion on pilot SA at the first and second level (i.e. information processing and comprehension)	47 participants aged 17-71 Flying experience ranged from 2 - 12,000 hours Participants held a mixture of licences from student to ATPL/military
Lawrynczyk, A (Canada)	2018	Exploring virtual reality flight training as a viable alternative to traditional simulator flight training	School of Computer Science, Carleton University	This study was conducted to inform the use of virtual reality (VR) technology as a flight simulation method that supports the training of high-risk scenarios and has major cost-saving potential Specifically, the research examined the user experience, cognitive load, and performance outcomes between a traditional 'broad-angle display' (BADS flight simulator and a VR environment.	41 participants, ages 18-32 2 participants were pilots and 1 other had some flying experience 38 participants had no aviation experience 18 participants indicated that they play video games at least once a week
Trinon, H (Belgium)	2019	Immersive technologies for virtual reality - case study: Flight simulator for pilot training	School of Management, University of Liège	Two research questions: 1) Is immersive virtual reality a potential tool for pilot training in the aviation industry? 2) Which immersive technology is the most suitable for hand tracking in virtual reality?	17 participants aged 18-25 8 males 9 females 10 participants had previously experience VR
Pennington, E; Hafer, R; Nistler, E; Seech, T; Tossell, C (USA)	2019	Integration of advanced technology in initial flight training	2019 Systems and Information Engineering Design Symposium	A persistent issue with the USAF's Pilot Training Next (PTN) programme has been a lack of data guiding (1) the ideal degree of integration into traditional pilot training and (2) the optimal amount of structure for student pilots' training experience The goal of this study was to evaluate the aforementioned PTN model when applied to the U.S. Air Force Academy's flight training program with special emphasis on the ideal degree of structure for airmanship success	60 cadets from the US Air Force Academy

Author/s (Base)	Year Pub.	Title	Pub.Type	Aims/purpose	Population / Sample size
Lewis J Livingston J (USA)	2018	Pilot Training Next: Breaking institutional paradigms using student-centred multimodal learning	Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)	The paper discusses the execution of the first Pilot Training Next (PTN) course from inception to insights, with a specific focus on exploring the use of Commercial Off the Shelf (COTS) technology to build affordable, portable simulation systems	20 student pilots and 13 instructor pilots (IPs) were specifically selected for the experimental program
Xi, Z McGowin, G Fiore, S Newton, O Sukthankar, G Oden, K (USA)	2020	Predicting student flight performance with multimodal features	13th International Conference on Social Computing, Behavioural-Cultural Modelling and Prediction and Behaviour Representation in Modelling and Simulation	To monitor and track complex knowledge and skill acquisition by applying machine learning (ML) algorithms to a mixture of physiological and performance-based indicators extracted from pilot training sessions	23 novice pilots with no prior flight training experience, aged 18-29 15 male 8 female
McCoy-Fisher, C; Mishler, A; Bush, D; Severe-Valsaint, G; Natali, M; Riner, B (USA)	2019	Student naval aviation extended reality device capability evaluation	US Naval Air Warfare Centre Training Systems Division	The purpose of this study was to assess the impact of XR on Student Naval Aviator (SNA) training performance outcomes. Specifically, the research team evaluated three Virtual Reality Part-Task Trainers (VR-PTTs) and one Mixed Reality Visual System (MRVS) on student performance in Primary, Intermediate Jet, and advanced Strike training The research team leveraged Kirkpatrick's Four Levels of Training Evaluation: 1) Reactions, 2) Learning, 3) Behaviour, and 4) Results	966 participants 958 Student Naval Aviators (SNAs) or recently-winged pilots 6 Instructor Pilots (IPs) / Pilot Training Officers (PTO) 1 Simulator Instructor 1 Flight Surgeon
Dymora, P; Kowal, B; Mazurek, M; Romana, S (USA)	2021	The effects of virtual reality technology application in the aircraft pilot training process	IOP Conference Series: Materials Science and Engineering	To obtain the optimal duration of exposure to virtual reality (VR) before the onset of physiological problems for the user that could affect teaching outcomes	17 participants (aged 21-23) 16 male 1 female Participants had no simulation or aviation experience
Whitson, R (USA)	2019	Training in a modern age	Department of Engineering, Arizona State University	To examine the levels of educational applicability for virtual reality in flight simulation training and ascertain if there is a significant difference between VR and training using a standard PC monitor	24 participants aged 20-25 2 groups of 12 participants Varying levels of familiarity with flight simulators and video games only

Author/s (Base)	Year Pub.	Title	Pub.Type	Aims/purpose	Population / Sample size
Gustafsson, A (Sweden)	2018	Use of head-mounted virtual reality displays in flight training simulation	Department of Computer and Information Science, Linköpings Universitet	Comparison between the current capabilities of commercially available VR HMDs to flight training simulators used today. To provide an evaluation of current VR HMD capabilities, a proof-of-concept prototype simulator with basic controls	30 participants 29 simulator engineers (non-pilots) 1 pilot
Ommerli, C; Mirzaagha, J; Ma, C; Bentham, K; Herdman, C (Canada)	2019	Virtual reality flight environments may tax working memory and disrupt prospective memory	20th International Symposium on Aviation Psychology	Considers three aspects (presence, interactivity, and fluency) of users' psychological experiences in virtual reality (VR) and how they might impact prospective memory (PM) (which is the ability to recall or perform an intended thought or action at a future point in time)	47 participants aged 17-71 Flying experience ranged from 2 - 12,000 hours Participants held a mixture of licences from student to ATPL/military
Oberhauser, M; Dreyer, D; Braunstingl, R; Koglbauer, I (Germany)	2018	What's real about virtual reality flight simulation?	Journal of Aviation Psychology and Applied Human Factors	In this article, a flight simulator based on immersive VR technology is presented: The Virtual Reality Flight Simulator (VRFS), which was developed by and is used at Airbus Group Innovations. To assess the fidelity of the system and the bias that is introduced by the virtual environment, the system is compared with a conventional hardware flight simulator	28 participants aged 25-72 The average total flight experience of participants was 2,485 hours All participants were qualified pilots although none had any experience with VR

Table 2

Data Extraction Table: Process and findings

Author/s (Base)	Method & Concept	Conclusions / Outcomes	Key findings that relate to the scoping review question
Pope, T (USA)	Qualitative: Multiple data collection methods including telecommunication and in-person interviews with subject matter and data experts. The site visit focused on collecting production and financial information in addition to interviewing PTN leadership to gain content for the qualitative analysis. Cost, production and quality comparison of PTN (VR flight training) with the current UTP system (legacy flight training)	Cost: Significant fixed and variable cost savings (financial analysis through accepted accounting practices) Production: Potentially significant increases in qualified pilot throughput (statistical analysis and interviews with SMEs) Quality: Conclusion limited due to time restrictions and lack of availability of quantitative data (quality comparisons from SMEs (instructors) obtained indicating PTN students to be 'leaps and bounds' ahead of their legacy UPT peers)	The strategic comparison of benefits indicates that PTN is superior from a cost and production standpoint, but further analysis is required to make a comprehensive quality comparison Potential organisational cost savings alone however should motivate organisations to investigate VR flight training as an option
Sheets, T; Elmore, M (USA)	Qualitative: A Likert Scale was utilized to gauge subjects' comfort levels An Adaptive Flight Trainer (AFT) was used to conduct a one-week trial with 40 subjects at Columbus, AFB to test cognitive, kinaesthetic, and effective learning Participants were trained and evaluated on the USAF 'visual box pattern, to an overhead break' (known as a 'circuit' in civilian aviation parlance) Performance, cognitive load, and eye-tracking data from the virtual and physical environments was captured A Likert Scale was utilised to gauge subjects' comfort level with VR and their perceived applicability of the environment to flight training	Performance improvement in altitude and airspeed control were recorded, as well as in procedural task completion in the OFT after 1.5 hours of Virtual Reality Learning Environment (VRLE) training (Observed indicators and outcomes by USAF instructor pilots and through data capture scripts)	Encouraging results that indicate the possibility that the TLST could reduce costs, be adaptable to an assortment of training requirements, and assist students in synthesising complex principles at a faster rate
Sakib, M; Chaspari, T; Ahn, C; Behzadan, A (USA)	Quantitative: Wearable devices were used to collect physiological data from participants. Qualitative: Mental workload (MWL), stress level, trait and state anxiety, and demographic and daily experience data are also gathered from each participant. Flight training, followed by relaxation to establish a baseline. Task 1, self-reporting, relaxation Task 2, self-reporting Time of completion and number of collisions were used to measure task performance, calculated as the average time to complete one loop, including the time lost due to collision	Quantifiable evidence based upon physiological data collected by wearable devices, that immersive VR training can be a viable proxy for training drone operators Results of the statistical analysis conducted on different physiological data and self-repots reveal that in most cases, no significant differences are found between VR and OD sessions	Concluded that immersive VR can be a suitable alternative for training and reskilling drone operators and predicting human outcomes in real-world flying conditions.

Author/s (Base)	Method & Concept	Conclusions / Outcomes	Key findings that relate to the scoping review question
Dalladaku, Y; Kelley, J; Lacey, B; Mitchiner, J; Welsh, B; Beigh, M (USA)	Quantitative: Comparative correlational research of prior class data Comparison of data from 5 traditional flight training classes against data from all (to date) ATN classes	The original summary statistics analysis supported the VR classes had a lesser standard deviation than the traditional classes (perhaps due to being taught by Quality Assurance instructors). However, the average score for the check rides almost exactly match the averages of the historical data. This analysis supports the conclusion that the ATN Program develops "just as good" aviators	It can be reasonably concluded from the data that the use of VR to supplement flight training does produce aviators of the same quality and competence as pilots trained in a live aircraft
Wilson, J; Scielzo, S; Nair, S; Larson, E (USA)	Quantitative: Repeated measures experiment – with each of three flight manoeuvres flown twice Pilot gaze data were collected in a mixed-reality training environment using a physical flight simulator, a virtual reality environment, and a gaze-tracking sensor for monitoring eye movements within the virtual space Heatmaps were synthesized from the patterns created by the gaze during flight and analysed by human instructors (Q1) and machine learning (ML) algorithms (Q2) for comparison of results	The performance of the ML multi-task model was comparable to a human instructor for verifying gaze quality. Therefore, it should be possible to deploy this model for applications such as (1) augmenting instructor observations or (2) training pilots to better scan for different manoeuvres automatically in a real-time environment.	Can display gaze pattern quality for students or qualified pilots. This can assist pilots (and instructors) in modifying their technique during practice sessions or in-flight
McGowin, G; Xi, Z; Newton, O; Sukthankar, G; Fiore, S; Oden, K (USA)	Quantitative: within-subjects research design, specifically varying the difficulty of the flight scenarios used in the VR environment Participants underwent a training tutorial on the basics of flight and their knowledge acquisition was assessed They all also engaged with the same set of practice and test flight scenarios, but the presentation order for the scenarios was randomized	This study set out to determine if different forms of knowledge assessment could predict performance in a complex VR flight simulator The study provides evidence that conceptual tests can tap into a deeper form of knowledge integration, and can be more diagnostic of learning efficacy, in this case, predictive of performance for aircraft operations in VR settings	This study extends the knowledge base for both the learning and cognitive sciences by demonstrating how a blend of traditional media with virtual reality can enhance conventional training. It also provides additional insight into the relationship between learning and transfer in virtual reality.
Ommerli, C (Canada)	Quantitative: Repeated measures experiment with participants completing two test sessions, the first in a traditional flight simulator, and the second in a VR flight simulator Participants were asked to complete a preliminary practice flight 35-45 minutes flight mission consisting of a four-leg route, which was completed in clear conditions. Participants were provided with a general flight plan and given specific directions At random intervals, the VR simulator was frozen 3 times and the VR HMD turned off - at this point, situational awareness questions (total 24) following the SAGAT protocol were administered	Findings from this study suggest that telepresence supports SA in VR flight training environments Telepresence experience is highly dependent on a pilot's perception of system interactivity. Avoiding events that compromise the continuity and cohesiveness of a pilot's experience of telepresence are essential for ensuring the integrity of the VR flight training environment and enhancing the likelihood of knowledge transfer between simulated and real-world contexts.	The results of this research provide meaningful contributions that can be used towards improving the design of VR flight simulators for training and assessment of pilot SA

Author/s (Base)	**Method & Concept**	**Conclusions / Outcomes**	**Key findings that relate to the scoping review question**
Lawrynczyk, A (Canada)	Quantitative: Repeated measures experiment - participant flew three circuits for each graphics condition Each participant flew three circuits of Pendleton Airfield while seated in the pilot site of the Cessna 172 flight simulator The research examined the user experience, the cognitive load, and the performance metrics in the BADS flight simulator condition against the same flight path and tasks using the VR environment	User Experience: No differences in BADS and VR in terms of queasiness, dizziness, or disorientation ratings between baseline and first exposure. Queasiness increases in VR after the second exposure Cognitive Load: Higher subjective ratings of mental workload were reported in the VR condition	This research suggests that although the user experience and performance metrics were comparable (apart from differences in maintaining airspeed), the VR experience likely causes an increased cognitive load on users compared to the BADS Completely replacing traditional flight training in a BADS environment with VR therefore could have undesirable side effects.
Trinon, H (Belgium)	Mixed methods Quantitative: Two-way repeated measures experiment Qualitative: Questionnaire A virtual cockpit was constructed in a virtual environment (VE), with an interactive yoke and four categories of interactive systems: switches, buttons, knobs and levers Two different types of technologies enabling to match the virtual hands to the real physical hands of the user have been implemented: The Leap Motion and VR gloves	Based on the results of the comparative study on immersion, the technical feasibility of a VR system for pilot training was confirmed Scores computed from the questionnaires showed that the proof of concept provides a VR experience that is more than satisfactory	The proof of concept was tested by technical pilots of ASL Airlines Belgium. Although only a proof of concept which requires some additional adjustments, the pilots stated that its potential for pilot training was real Based on all the results presented it may be concluded that virtual reality is a potential tool for pilot training in the aviation industry
Pennington, E; Hafer, R; Nistler, E; Seech, T; Tossell, C (USA)	Mixed methods Quantitative: Repeated measures experiment Qualitative: VR hand and cybersickness questionnaires Participants were pseudo-randomly assigned to three independent groups with varying degrees of structure 1) High Structured, 2) Scaffolded, and 3) Low Structured Groups The groups represented a spectrum of VR-training curriculum structure ranging from a rigid, lineal objective-completion model (akin to traditional flight training) to an unguided, Montessori-like model Hand Questionnaire (HQ). It is composed of 4 items which are rated based on a continuous scale from 0 to 10 A cybersickness questionnaire was also filled out by the participants.	Initial effectiveness data indicated an increased level of perceived self-efficacy in coordination with increased virtual reality simulator time as well as an accelerated rate of positive transfer to real aircraft from the strictly structured and scaffolded groups	The results of this study do allow for initial recommendations for forthcoming airmanship training and undergraduate pilot training augmentation efforts across the Department of Defence.

Author/s (Base)	Method & Concept	Conclusions / Outcomes	Key findings that relate to the scoping review question
Lewis J Livingston J (USA)	Qualitative: After-action review (AAR), conducted within one hour of simulated or live flight The VR simulator environment provides multiple types of data analysis, specifically real-time feedback, conducted during simulated flight; after-action review (AAR), conducted within one hour of simulated or live flight; and post-processing, provided days, weeks or months after the fact and entails more computation-intensive analysis	Of the 20 students that started PTN, 13 completed the course, graduating with wings in just half the time of the traditional UPT training method Traditional UPT adheres to a strict schedule while PTN allows students to move at their own pace through the curriculum and practical exercises The team believes this student-driven approach will reveal learning patterns that can help inform track selection	On average, PTN students completed their first successful solo flight on their 7th or 8th flight while traditional UPT students solo, on average, on their 13th or 14th flight Long term, PTN expects to use its data analysis to inform the development of cognitive models which will be used to predict the success of the trainee in their future training PTN is capable of developing these competency models due to its focus on emerging technologies and data collection
Xi, Z McGowin, G Fiore, S Newton, O Sukthankar, G Oden, K (USA)	Mixed methods Quantitative: Correlational design Qualitative: Questionnaire Training in five sections: aircraft model; aircraft controls; flight manoeuvres; flight instruments; simulator tasks Participants were tested on the concepts they learnt using a questionnaire consisting of 10 recall questions, 10 descriptive questions and 10 conceptual questions	The experiments show that it is feasible to accurately predict student failure on simple flight tasks from visual attention features gathered from the initial flight phase, combined with knowledge mastery features The results affirmatively answer all research questions	The finding in this study provide important stepping stones towards the long-term vision of scalable, automated delivery of flight instruction using off the shelf virtual reality headsets
McCoy-Fisher, C; Mishler, A; Bush, D; Severe-Valsaint, G; Natali, M; Riner, B (USA)	Mixed Methods Quantitative use of Training Integration Management System (TIMS) data from former and current trainees Qualitative collection of the comprehensive questionnaire responses, online or in-person collection of responses to the flight log questionnaire, a wrap-up survey at the end of data collection, in-person focus groups with CNATRA stakeholders Researchers required that all SNAs be given free access to the XR devices. Instructor support was not built into the delivery of the devices; therefore, SNAs did not participate in structured training events with the VR-PTTs. Instead, they engaged in free play or self-guided study sessions with the devices as they desired The MRVS required instructor presence to operate the OFT with which it was integrated, so participants who used the MRVS received traditional OFT instructor guidance during MRVS sessions	1) Reactions: All feedback considered, participants reactions were neutrally favourable to the devices. 2) Learning: Results may indicate either that COTS VR/MR flight trainers are less valuable for basic flight skills than for more advanced skills, 3) Behaviour: Conclusions from this section suggest that exposure to VR/MR devices is associated with improved performance. 4) Results: Learning-level data from the T-45C VR/MR devices suggested that they may reduce reflys and events needed to meet MIF.	Quantitative performance data may support a link between the XR device usage and performance improvement (fewer reflys, marginals, and events to meet MIF). Further, controlled experimental research is needed to clarify the relationship In addition, self-report feedback and focus groups for all four devices indicates that there are perceived benefits provided by XR flight trainers, beyond what is currently available in UTDs and OFTs With noted upgrades, XR systems have the potential to improve performance and can cover the gap in current training

Author/s (Base)	Method & Concept	Conclusions / Outcomes	Key findings that relate to the scoping review question
Dymora, P; Kowal, B; Mazurek, M; Romana, S (USA)	Qualitative 8 question survey A sample training application was created in a VR environment to familiarize students with the essential elements of a Socata TB-9 "Tampico" aircraft cockpit The exercise was programmed as a fully immersive VR lesson that replicated the interior of the aircraft, based on photographs, to facilitate the learning of pre-start cockpit procedures	The study draws no supported conclusions and fails to answer the RQ.	
Whitson, R (USA)	Quantitative between subjects, quasi-experimental method During the pre-test, participants flew over an urban environment Under the 'simple' post-test landing condition, participants flew over large fields with scattered trees	Results do not appear to support the idea that virtual reality is superior to training with a PC monitor. Once familiarised with the set-up, however, there was some data to suggest that the VR group seems to perform better in the rich textures' environment	
Gustafsson, A (Sweden)	Qualitative questionnaires where the moderator first answered some factual questions connected to the participant's performance and then asked the participant to answer some questions connected to the usability attributes The focus of the thesis will be limited to professional, low-fidelity, screen-based flight training simulators and how a VR HMD can be used to complement and improve such a setup	• The resolution in the HMD meets the minimum requirements • The refresh rate exceeds the minimum requirements • The field of view (FoV) is larger than the specified minimum requirements Contemporary VR HMDs did meet the technical requirements of a flight training simulator	The conclusions showed that VR HMDs could be used in some areas of pilot training simulations, however, there are several areas that either needs more research or need to be developed further to be able to fully utilise the capabilities of VR HMDs
Ommerli, C; Mirzaagha, J; Ma, C; Bentham, K; Herdman, C (Canada)	Qualitative questionnaire Randomised auditory PM tasks and tests of working memory using with involved freezing the simulation to ask situational awareness questions	The results suggest that experiences of fluency or intense concentration in VR significantly tap into working memory resources. Content belonging to the VR environment may engage fluency, which could, in turn, divert attention otherwise needed for PM Presence and interactivity were shown to positively influence PM and working memory. Presence, in particular, had a strong positive effect on both cognitive processes	Fluency: Findings are aligned with previous research which suggests that highly vivid sensory experiences in VR create a strain on cognitive resources. Presence and interactivity: VR environments with high representational fidelity support enhanced situation awareness, proposing that vivid design facilitates continuity in presence through enhancing the "realism" and "believability" of the experience.
Oberhauser, M; Dreyer, D; Braunstingl, R; Koglbauer, I (Germany)	Quantitative: Repeated measures experiment The flight task starts with a short taxiing phase from the parking position, a take-off, and a left-hand traffic pattern at an altitude of 2,000 ft	Most participants were able to safely and reliably complete the flight task after a short acclimatization phase in the virtual environment	The results show that the fidelity of the VRFS is significantly lower compared with the fidelity of a conventional flight simulator and thus cannot substitute the latter, particularly if the pilot's behaviour and performance are to be as close to reality as possible

2.4 Discussion

2.4.1 Summary of Evidence

The ScR identified eighteen studies of interest published between 2018 and 2021 that could assist in answering the research question.

Of these studies, the majority were presented at conferences and subsequently published as conference proceedings and not as journal articles. It could be suggested that this is indicative of the speed at which technology is advancing in this area (i.e., quickly rendering technology & study data obsolete), making the delays sometimes associated with publishing in academic journals seem less attractive (Ernst, 2006; IEREK, 2018). Or, it might be concluded that some of the studies lack academic rigour and may not stand up to the stringent peer-review process of high-level journal publication (Ernst, 2006). Another alternative is that the author/s could be continuing their work, including the incorporation of conference feedback, in this area and have, or intend to, submit the finished study to an academic journal for publication in the future (IEEE ComSec, 2017). In any case, it is unlikely that these papers will have been subjected to the level of scrutiny normally associated with journal publication (Aragon, 2016).

Most of the included studies were conducted by researchers based in the United States, with seven of the eighteen studies, and the majority of the participants originating from the US military. These data suggest that the US military complex is currently investing significant time and resources into researching the potential benefits of xR for pilot training and is also reporting optimistic findings through some of their initiatives (i.e., Pilot Training Next). A potential explanation for this is that few, if any, civilian aviation organisations (e.g., FTOs and academia) have the resources and financial capability to match the US military, therefore, in contrast, existing research from these sources appears to be limited in scale and number. Additionally, few studies from the civil sector were solely focused specifically on flight training, instead seeming to concentrate on nuanced areas of training such as learning, human-machine interaction and other human factors.

The majority of both the quantitative and qualitative evidence included in this review supports the potential of xR to be used as an instructional aid in the training of pilots who are currently using traditional flight training methods. The studies suggest that participants that undergo xR flight training are at least as good as those trained using traditional means (Dalladaku et al., 2020; Pope, 2019; Sakib et al., 2020). There is also evidence to suggest that xR flight training, in concert with traditional flight training, could decrease training time (Lewis & Livingston, 2018; McCoy-Fisher et al., 2019; Pope, 2019; Sheets & Elmore, 2018), reduce costs (Pope, 2019; Sheets & Elmore, 2018) and lower the environmental impact of flight training overall (Pennington et al., 2019; Pope, 2019).

Some studies noted that xR flight training has some noteworthy limitations. VR, in particular, can result in Breaks in Presence[3] [4] (BIP) (Chung et al., 2021) (i.e., feeling *disconnected*) between the participant and the physical world they occupy (e.g., a VR flight simulator with physical

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[3] Presence (or telepresence as it otherwise known) is an inside-out view of the world where the participant sees and interacts with the VE (e.g., an aircraft cockpit) just as they might if they were physically present. It is the sense one gets of being in the virtual environment (VE).

[4] Breaks in presence (BIP) are moments whilst exposed to a VE that a participant becomes aware of their real world setting and their sense of presence in the VE becomes disrupted.

cockpit controls). This BIP can result in restrictions in operation, particularly when the pilot is required to engage with particular aspects of the physical cockpit environment/equipment (e.g., buttons, dials and switches) (Laptaned et al., 2019; Lawrynczyk, 2018; Oberhauser et al., 2018). MR, which combines images of the physical environment and VE, has the potential to overcome this limitation as it develops (Dalladaku et al., 2020; Howard, 2019). It is also reasonably common to feel the effects of simulator or cybersickness (e.g., cybersickness symptoms include nausea, dizziness, disorientation and headaches and are related to classical motion sickness) (McHugh, 2019) during xR exposure, particularly if a participant is susceptible to motion sickness, or new to xR (Lawrynczyk, 2018; Oberhauser et al., 2018). This can often, but not always, be overcome with continued exposure over time that may lead to the participant becoming desensitised (McHugh, 2019). It is worth mentioning that conventional simulators as well as real aircraft are also known to cause motion sickness (Masson, 2021).

2.4.2 Limitations

There were at least three potential limitations identified during this ScR. Firstly, during the search and study identification phase, it is possible that not all of the studies relevant to answering the research question were successfully identified. Secondly, it is also possible that studies exist that have not, for various reasons (e.g., publication bias) been made publicly available. Thirdly, due to financial constraints, only studies published in English were considered, which prevented the potential inclusion of six of the identified studies. Lastly, the ScR was carried out in partial fulfilment of a Master of Aviation degree. Massey University thesis protocols stipulate that research projects must be conducted solely by an individual. It has not, as a result, been possible to engage the services of secondary reviewers (i.e., second and/or third author). In accordance with these rules, all screening of studies, data extraction and compiling of results was carried out in isolation without external input. Notwithstanding this, ScR best practice, following the JBI Manual for Evidence Synthesis, Chapter 11: Scoping reviews, was adhered to as far as possible. The above are acknowledged as limitations of this ScR.

2.4.3 Suggestions for Future Research

As is evident from the paucity of eligible studies focusing on the use of xR technology and/or VRFS use in flight training (particularly in the civil sector) that there is scope for more research to be undertaken. The greater the amount of data and level of understanding on a topic area such as this will enable those responsible for deciding what future iterations of flight training will entail. Specifically, to assist in achieving this goal, it is suggested that more research should be undertaken in areas such as BIP/disconnect. Here the potential benefits of MRs perceived ability to reduce these effects could be further investigated. A comparative study involving civil FTOs could be conducted to assess differences between student pilots groups, some of whom used VRFSs in their training. In concert with a comparative study, a cost-benefit analysis could also be undertaken to compare the costs of differing flight training approaches (i.e., traditional versus VRFS) to gather data that might support the suggestions of cost-saving made in other studies.

2.4.4 Conclusions of Scoping Review

The purpose of this ScR was to 1) answer the research question; 2) provide an overview of the topic and 3) determine the value of conducting a full systematic review.

Despite the aviation industry's proclamations to limit its environmental impact with initiatives such as CORSIA, as well as reducing training time and cost, while also increasing pilot throughput, only 18 studies that satisfied the inclusion criteria were identified. This number is low when considering the technological potential, level of innovation and the investment currently being seen in xR technology. From the limited number of studies available, however, there was some evidence to suggest that xR flight simulators could successfully be used in support of traditional flight training.

Overall, this ScR determined that there is a lack of empirical, peer-reviewed studies in the area of xR flight training. In light of this finding, further investigations into whether xR can satisfactorily deliver an enhancement to traditional flight training methods are required. This is something that could be addressed by academic institutes, particularly those with close ties to commercial aviation. To redress the imbalance that currently exists with military studies, research of an empirical nature involving civil FTOs should be undertaken as a priority, so the results can be better applied to airline and civil aviation. It is suggested that a longitudinal study involving both instructors and students at a large FTO would in part fulfil this requirement and potentially provide data that could also apply to other commercial FTOs.

It is concluded that, at this moment, not enough high-quality empirical evidence exists to warrant the conducting of a full systematic review.

Chapter Three: Focus Group Study

3.1 Introduction

3.1.1 Reason for Conducting a Focus Group (FG)

As mentioned in Chapter One, during the initial analysis of the data gathered for the ScR, few studies were found to exist that focused solely or even primarily on civil flight training, civilian student pilots or civil flight instructors. Secondly, although it might be suggested from the results of the ScR that VRFSs have the potential to assist in pilot flight training, none of the studies detail the thoughts, opinions, or attitudes of flight instructors in any significant detail. For these reasons, it was decided to conduct an FG study, to complement the data gathered during the ScR. The intent of the FG study was to gather data from individuals who were directly involved in civil flight training, and thus, were in a position to provide informed commentary on how xR technology (i.e., VRFSs) might be integrated and used.

The remainder of this section provides the details of two FGs that were conducted using qualified professional flight instructors employed at New Zealand's largest FTO (described henceforth as *the FTO*). The FGs were conducted in such a way as to encourage open-ended discussion[5] by allowing the flight instructors to express their views and opinions on the topic freely and organically. The resultant data is intended to provide further insight into the pros and

[5] For the purposes of these FGs an open-ended discussion format was deemed preferable over moderator led discussions, wherein the topic and direction of the conversation is controlled and led by the moderator.

cons of VRFSs and assist decision-makers in informing policy regarding the potential adoption of these simulators as flight training devices.

An alternative to conducting FGs that was briefly considered was to carry out expert interviews. Interviews were ultimately discounted, as FGs are considered to be superior to interviews when used in the exploration of collective phenomena (e.g., flight training idiosyncrasies), as opposed to issues of an individual nature (Robson, 2002). Another advantage of FGs, over one-on-one interviewing, centres on the exploratory nature of this research. FGs are an effective and efficient means of generating data and, as such, are most often used for research of this type when, as in this case, little is known about the subject (Denzin & Lincon, 2000; Keyton, 2011; Novak & Buddenbaum, 2001; Robson, 2002; Stewart et al., 2007).

3.1.2 Focus Groups

FGs comprise a group of participants that have been selected and brought together to discuss and comment on a particular research topic (Powell & Single, 1996). Originating from the Bureau of Applied Social Research at Columbia University in the 1940s, FGs were originally used to gauge the effectiveness of wartime propaganda (Bloor et al., 2011). FGs are a form of group interview but differ in that group interviews focus on questions and answers between the researcher and the participants, whereas FGs depend on the interaction between participants within the group (Morgan, 1997b). Hence the distinction between the two methods is that FGs concentrate on the insights and data produced by the interaction between group participants (Gibbs, 1997).

Morgan (1997a) stated that FGs are better suited to exploratory research as they provide the opportunity to give control of the conversation to the group. This approach stimulates further ideas allowing participants to generate their own questions and follow a unique conversational direction (Kitzinger, 1995). Thus, partaking in group discourse allows participants to bounce ideas off one another's responses, generating a greater variety of information for the researcher (Hocking et al., 2003). They may also stimulate responses and ideas from participants who might otherwise not have been contributing (Henn et al., 2005). Furthermore, FGs can be particularly beneficial when ideas are being sought in an attempt to develop an understanding of a situation, as they often generate more critical comments from participants than one-on-one interviews (Kitzinger, 1995).

Academic FGs, as opposed to those used extensively in commercial market research, differ in respect to the scientific techniques employed by academic researchers to analyse the data (Bloor et al., 2011). As with ScRs, FGs lend themselves to research of an inductive nature as they can be used to generate broader meanings from a data set in order to identify patterns and relationships (Dudovskiy, n.d.). Post FG sessions, researchers rely on the systematic analysis of media, such as audio recordings and verbatim transcripts that are thematically coded to derive patterns, meanings, processes and norms (Bloor et al., 2011). FGs, therefore, are a useful tool that can be used to provide a valuable means of documenting the complexities through which group norms and meanings are shaped, elaborated upon and applied in a real-world context (Bloor et al., 2011).

3.1.3 Uses of Focus Groups: Strengths and Challenges of the method

Group interaction enables participants to ask questions of one another and provides the opportunity to re-examine their understandings of specific individual experiences. Kitzinger (1995) argued that the interaction and language used between FGs participants emphasise their view of the world, their values and attitudes about a situation.

If the participants of an FG work well together, trust develops and the group may discuss the solutions to a problem collectively (Kitzinger, 1995). FGs can produce information in such a way as to allow a researcher to discover why an issue is relevant, as well as what is relevant about it: if multiple interpretations are presented by participants, multiple reasons for these behaviours and attitudes may be more readily expressed (Morgan, 1997b).

Another potentially valuable advantage of FGs is that they can act as a vehicle for change for users, participants or organisations (Race et al., 1994). For example, Gross and Leinbach (1996) found that participants who took part in FGs experienced a feeling of liberation by being allowed to voice their opinions in public. In another study, Smith et al. (1995) reported that changes took place at management level as a direct result of participant feedback received during FG discussions regarding the delivery of services to customers.

As with all research methods, FGs have limitations. Some of these may be overcome with considered planning and moderating, but others are unavoidable and unique to this approach (Gibbs, 1997). In FGs the moderator has less control over the data produced than with one-on-one interviews or indeed quantitative studies (Morgan, 1997b). By nature, FG research is open-ended and cannot be predetermined entirely. In addition, other than keeping participants focused on the topic, and having less control, the moderator has to allow participants to talk to each other, ask questions and express doubts and opinions freely (Gibbs, 1997). There is a risk that participants may also not be expressing their personal, individual opinion either, instead, communicating in a specific setting, within a specific culture. As such, it may sometimes prove problematic to identify an individual message or meaning (Gibbs, 1997).

Finally, FGs can be difficult to organise and present issues when trying to gather a representative sample, and may deter particular types of people from taking part (e.g., shy, unconfident individuals). Also, because FGs are not fully confidential or participation anonymous, there is a requirement to be willing to share your thoughts and be able to trust the other participants in the group with confidentially (Gibbs, 1997).

3.1.4 Summary and Justification

The decision to use this method of researching this field is supported by the numerous examples of FG studies already having been performed/published in aviation-specific research. These studies include, but are not limited to: Evaluation of the course of the flight simulators from the perspective of students and university teachers (Kaysi et al., 2016), Public engagement on aviation taxes in the United Kingdom (Ryley et al., 2010), The analysis of aviation safety action programs in aviation maintenance (Patankar & Driscoll, 2004), and Cleared to disconnect? A study of the interaction between airline pilots and line maintenance engineers (Fisher, 2016).

As has been noted, with an inductive approach, the themes that are identified are strongly linked to the data, similar to that of grounded theory (Patton, 1990). The FG method of data gathering, coding and analysis was therefore well suited to the inductive and exploratory nature of this research, and to answer the research question—RQ2. It is, for these reasons, it was adopted.

3.1.5 Research Question (RQ2):

This section of the study focuses on addressing the following research question:

> *What are the opinions of professional civilian flight instructors toward using virtual reality flight simulators as an adjunct to traditional flight training methods?*

3.1.6 Conduct and Intent of the Focus Group:

There is a large amount of information published on the conduction of FGs, however, in their pioneering work, Merton and Kendall (1946) suggest important considerations for FG design and improvement. They stipulated that participants should have specific experience of, or opinions about, the topic under investigation; that a moderator guide should be used (see Appendix B); and that the subjective individual experiences of participants be explored concerning the research questions (Gibbs, 1997).

In line with these suggestions, the FGs were conducted with the intent of: 1) capturing data regarding participants attitudes, opinions, feelings, beliefs, experiences and reactions about using VRFSs in flight training, 2) the categorising and coding of said data, 3) answering the research question by drawing on the participant responses and analysing the themes that emerged from these, and 4) providing further data on the topic and dissemination of any findings to relevant or interested parties (e.g., FTOs, aviation authorities, aviation researchers and flight simulator technologists).

3.1.7 Ethics Approval

Prior to commencement, an application for ethics approval to conduct research using human participants was made to Massey University Human Ethics Committee (MUHEC). Approval was received on 08/06/2021 (Ref: 4000024545) and can be viewed in Appendix A.

3.2 Method

3.2.1 Focus Groups

As was discussed in Chapter One, due to the nature of the research question and the focus on a little known area of interest (Stewart et al., 2007), a qualitative approach was employed to gather data that would be high in detail and sufficiently nuanced to provide insight into the complexities of flight training and flight simulation. Two such qualitative methods were initially considered: in-depth one-on-one interviews and FGs. One-on-one interviews were quickly discounted in favour of FGs as the latter was considered much more suited to the exploratory nature of the study being undertaken (Morgan, 1997a).

This study was concerned solely with gathering data from FIs on their individual/collective attitudes in an area of thus-far limited research. For this reason, the FG method was preferred because of the open-ended questioning that could be adopted (Stewart et al., 2007). The intent was to encourage the participants to explore the issues of importance to them, in their own words, creating their own questions and pursuing their own priorities (Kitzinger, 1995).

3.2.2 Sample Frame and Eligibility

To be eligible for selection in this study participants had to be a qualified *A, B* or *C* category (cat) FI currently employed at the FTO. The sample frame consisted of $N = 34$ potential FI participants. There are a number of non-probability sampling methods that can be employed to select participants for FGs, with convenience sampling typically being the most common (Stewart et al., 2007). FIs at the FTO work on a 6-day rotating roster system (i.e., 4 days on followed by 2 days off). During the study planning stage, it was decided that the only practical time when the majority of potential participants would be available would be on a weekday, during normal flight operation hours. As the FIs work on a roster, this further restricted the number of available participants depending on the day (i.e., rostered on to work, or rostered off). Due to these limitations, convenience sampling was the only plausible option that would enable participants to meet in groups. As a consequence of these restrictions, it is accepted that the results of this study are limited in terms of their external validity (Robson, 2002).

3.2.3 Number of Sessions

There are limited guidelines regarding how many FG sessions should be conducted in any particular study. Generally, it is suggested that between three and five group sessions are held (Keyton, 2011; Lewis-Beck et al., 2003; Morgan, 1995; Stewart et al., 2007), although Morgan (1995) contends that this number can be decreased if:

1. the groups are highly homogenous
2. the number of populations being compared is low
3. there is high moderator involvement

Preferably, FG sessions should continue until data saturation is reached, or no new information is forthcoming, which usually occurs after three or four sessions (Lewis-Beck et al., 2003). It is acknowledged that FGs tend to be very time and labour intensive and it is consequently advisable that sessions be limited to the minimum number needed to satisfy the researcher that adequate data has been collected (Bloor et al., 2011; Khan et al., 1991; Morgan, 1995). To ensure that the generated data was not simply the result of a unique group dynamic or arrangement (Hocking et al., 2003; Morgan, 1995; Stewart et al., 2007) and because of the small sample frame, difficulty scheduling FIs and other time constraints, it was decided to conduct a total of two FG sessions.

3.2.4 Number of Participants and Group Composition

FGs are most suited to having between six to twelve participants (Morgan, 1997a; Novak & Buddenbaum, 2001; Robson, 2002) as larger groups than this can be difficult for the moderator to control, resulting in limited input from some participants due to time limitations (Keyton, 2011; Stewart et al., 2007). If on the other hand participants are particularly knowledgeable on the topic of discussion, or the topic is complex and the participants were recruited specifically for their expertise, there is a strong case for using smaller groups (Bloor et al., 2011; Morgan, 1995, 1997a). Participant numbers of between six and twelve are often reported in studies, however, in reality, published studies featuring FGs typically have lower numbers of participants, citing M = 4.4 participants per FG (Bryman, 2004). With this in mind, it was decided that small FG groups would be appropriate.

Due to the nature of the shift rostering system mentioned participants who were on similar roasters and would therefore be at work on the same days proved to be most suitable. Flight training schedules and other operational duties are typically planned one month in advance. As a result, the FGs has to be planned four to six weeks ahead of time. Of the total sampling frame, n = 28 (82%) male and n = 6 (18%) female. Of these n = 6 (18%) were A cat FIs, n = 19 (56%) were B cat FIs and n = 9 (26%) were C cat FIs.

From the total sample frame, ten FIs were identified as potential participants. To allow for clearer generalisability, as suggested by Jager, Putnick and Bornstein (2017), it was decided, as far as practicable, to maintain the general homogeneity of the overall sample frame with the groups. This approach is considered a positive alternative to conventional or heterogeneous convenience samples (Jager et al., 2017).

3.2.5 Focus Group Guide

The duration of the FGs was restricted to between 60 and 90 minutes, which is generally in line with accepted practices (Bloor et al., 2011; Center for Disease Control and Prevention, 2018; Keyton, 2011; Morgan, 1995). Due to the exploratory nature of this research, open-ended questions were adopted in the hope that this would encourage more dialogue and promote discussion rather than just answering a series of questions. Only one question was asked at the commencement of the FG (see 2.4.1), although other brief pointers were prepared to keep the conversation on topic, or in the event of the dialogue stalling. An FG guide (see Appendix B) was produced as an aide-mémoire for the moderator in order to assist with the smooth facilitation of the FGs.

3.3 Procedure

3.3.1 Conducting the Focus Groups

Permission to approach and utilise flight instructors for the purposes of participation in an FG study was sought and received by the CEO & Chief Flying Instructor (CFI) of the FTO.

Once a number of potential participants had been identified, they were emailed to ask if they would be willing to participate in a research FG and advised what this would entail, including time commitment. Those that responded affirming their willingness to participate were given an information pack containing the following:

1) An explanation of VR, details of the research project and the intent of the FG (Appendix C).
2) A MUHEC consent form which all participants were required to sign (Appendix D).
3) A demographic information form for collecting participant statistics (Appendix E).

Next, within one week of the FG session that they were to partake in, each of these FIs was given the opportunity to fly and familiarise themselves with the VRFS (detailed in section 3.3.2).

Prior to commencing the FG, the participants were again reminded of their rights, including their right to withdraw at any time: as stipulated by the Massey University Human Ethics Committee (MUHEC) approval (MUHEC, 2021). Following this, an icebreaker activity was undertaken where the participants had to correctly sort, in chronological order, several pictures showing pieces of VR hardware through the ages.

The FG proper commenced with the following broad open-ended question to prompt initial discussion:

> *It has been suggested that virtual reality technology could be used in flight training, and if implemented could potentially save time and money. As flight instructors, has anyone got any thoughts on this?*

This question was intended to facilitate participants exploration of the issues of importance to them using their own words. The occasional, short, brief, intervention was required by the moderator either to keep the conversation on topic or when the dialogue stalled (e.g., to give a reminder of a point touched on by the participants previously), following these interventions the moderator once again disengaging, allowing the discussion to continue organically.

Each FG was audio recorded using Otter.ai (Otter.ai, 2021) software that had been installed specifically for this purpose on an Apple iPhone and an Apple iPad. Otter.ai is a mobile device app that allows the recording of voice conversations in real-time. Once captured these conversations are synchronised with the Otter website where they can be accessed for later transcription, editing and export to NVivo 12 Pro (detailed below). Data collection, and thereafter storage, was conducted in accordance with the particulars submitted in Massey University Human Ethics Committee application. Both FGs were conducted within one week of each other in July 2021, using the meeting-room facilities at the FTO's primary operations facility.

3.3.2 VR Flight Simulator Equipment

The VRFS hardware (see Figure 4) consisted of a base, chair and COTS gaming controls: flight stick (Virpil VPC Mongoos), throttle quadrant (LogiTech), rudder pedals (MFG Crosswind) and a VR HMD (Varjo VR-2 Pro). The VRFS was controlled by a high-end gaming PC[6] running the latest version/build of X-Plane 11 that featured a G1000 equipped DA40 aircraft, as operated by the FTO. The virtual environment (VE) in the VRFS depicted a realistic representation of the FTO's home base airport and surrounding area.

Figure 4

The Virtual Reality Flight Simulator (VRFS) at the FTO where the researcher was situated.

3.3.3 Participant Details

Due to operational requirements and conflicting commitments on the days of the FGs, participant numbers had to be adjusted from the originally planned *n* = 5 per FG. This resulted in the first FG comprising *n* = 4 participants, while the second contained *n* = 6. Unfortunately, the FI who had to withdraw was an 'A' cat FI who could only be replaced at such short notice with a 'B' cat FI: this resulted in a slight skewing of the FI ratio per category when compared to the sample

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[6] High-end gaming PC: HP EliteDesk 800 G4. Processor: Intel(R) Core(TM) i7-8700 CPU @ 3.20GHz 3.19 GHz. RAM: 64.0 GB. GPU: Nvidia GeForce RTX 2080

frame. The final participants comprised, $n = 1$ (10%) ‘A’ cat, $n = 6$ (60%) ‘B’ cats and $n = 3$ (30%) ‘C’ cat FIs.

Of the $N = 10$ participants that took part in the FGs, the modal age band was 25–34 years. Of the total, 9 (90%) held a bachelor's degree. Years of flying experience ranged from 4–24 years ($M = 7.75$, $SD = 5.89$), with total flight time ranging from 414–5000 ($M = 1379.00$, $SD = 1323.33$) hours. Years of flight instructing experience ranged from 0.5–15 ($M = 4.15$, $SD = 4.13$) years, with total number of instructor flight time ranging from 89–4200 ($M = 979$, $SD = 1188.19$) hours. [Andrew, do you think a table would add anything here?]

FG session lengths were 1:02:39 for the first FG, and 52:30 for the second: providing a total of 1 hour, 55 minutes and 9 seconds of recorded data.

3.4 Analysis

3.4.1 Thematic Analysis

To produce the richest description of these data it was important to determine the best methods to use prior to commencing thematic analysis on the FG data (Braun & Clarke, 2006). It was decided that providing a rich thematic description of the entire data set to provide a sense of the predominant themes would be the best approach (Braun & Clarke, 2006). As a result, in this study, the themes identified needed to represent an accurate reflection of the content of the entire data set. Using this method some depth and complexity were necessarily lost but the rich overall description was preserved. Braun and Clarke (2006) stated that this approach might be particularly useful when investigating under-researched areas, or when working with participants whose views on a topic are not fully known, as was the case in both instances here.

3.4.2 Inductive Thematic Analysis

Themes within a data set can be identified in one of two ways in thematic analysis: inductive, 'bottom-up' (Frith & Gleeson, 2004) or deductive, 'top-down' (Boyatzis, 1998; Hayes, 1997). In an inductive approach, the themes identified are strongly linked to the data themselves, similar to that of grounded theory (Patton, 1990). The subsequent inductive analysis was one of coding data without attempting to make it fit into pre-existing frameworks or analytic preconceptions (i.e., data-driven). It is important to note, however, that researchers cannot free themselves of their theoretical and epistemological commitments, and data are not coded in an epistemological vacuum (Braun & Clarke, 2006), as such research bias may still have an influence.

3.4.3 Semantic Themes

Thematic analysis typically focuses on just one *level*. As such, a decision had to be made to determine the level at which themes were to be identified: semantic (i.e., explicit) or latent (i.e., interpretive) (Boyatzis, 1998; Braun & Clarke, 2006). The semantic approach identifies themes within the explicit or surface meanings of the data, and therefore the analyst is not seeking anything beyond what a participant has said. Preferably, the analytic process would progress from description, where the data have been organised to show patterns in semantic content and then summarised, to the data interpretation (Patton, 1990).

3.4.4 Essentialist/Realist Thematic Analysis

The final decision involved epistemology. Research epistemology guides what can be said about the data and informs how meaning is theorised. With an essentialist/realist approach one's motivation, experience, and meaning can be explained quite easily as there is a simple relationship between meaning and experience (Potter & Wetherell, 1987; Widdicombe & Wooffitt, 1995).

Thematic analysis involves searching across a data set to find repeated patterns. When considering meanings across a whole data set, Braun and Clarke (2006) suggested that the inductive, semantic and realist approaches cluster together. Therefore, these methods were determined to be the best combination for analysing the type of data gathered for this study.

3.4.5 Data Analysis

Braun & Clarke (2006) advocate that thematic analysis is a useful and flexible method for conducting qualitative research. In their 2006 paper *Using thematic analysis in psychology*, they provide a *six-phase* outline *"…*to those wanting to start thematic analysis, or conduct it in a more deliberate and rigorous way, and consider potential pitfalls in conducting thematic analysis" (Page 77).

3.4.5.1 The Braun & Clarke (2006) six-phase approach guidelines:

3.4.5.1.1 Phase One: Familiarisation with the data:

Researchers must become very familiar with their data. To assist in achieving this the transcription of the audio files was completed at this stage. (Braun & Clarke, 2006) suggest that the transcript should be a rigorous and thorough *verbatim* account of all verbal, and sometimes, nonverbal communication. To achieve this, thorough, repeated *active* reading of the transcriptions was carried out—searching for meaning and patterns. Note-taking on emerging themes was also commenced at this stage. Although time-consuming, this phase must not be skipped (Braun & Clarke, 2006).

3.4.5.1.2 Phase Two: Generating initial codes

The process of coding is part of the analysis (Miles & Huberman, 1994), as data is being organised into meaningful groups (Tuckett, 2005). This phase involved coding interesting features of the data systematically across the entire data set and collating data relevant to each code, as suggested by Braun & Clarke (2006). Codes were not mutually exclusive with sections of the transcript being coded multiple times to different themes. Transcript segments were also not limited to any particular number of words, lines or sentences. In this way, both a fine-grained and broad-brush approach could be adopted, a technique useful in enhancing analytical rigour (Kidd & Parshall, 2000). In this study, the transcription files were exported from Otter in text format and imported to NVivo 12 Pro, a qualitative data analysis software program, for thematic analysis and initial coding.

3.4.5.1.3 Phase Three: Searching for themes:

Here codes were collated into potential themes, gathering all relevant data to each theme under one (or more) codes. Mind-maps and word-clouds (see Figure 5, Figure 6 & Figure 7) were used at this stage to assist in visualising the themes. During this phase, consideration was given to the relationship between codes, themes, and different levels of themes (e.g., main overarching themes and sub-themes within them) (Braun & Clarke, 2006).

3.4.5.1.4 Phase Four: Reviewing themes

During this phase further refinements were made to ensure themes worked in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic ‘map’ of the analysis (Braun & Clarke, 2006). Level 1 was carried out at the level of the coded data extracts to ensure they formed a coherent pattern. Where coded data did not achieve this, it was moved to a more appropriate theme, a new theme was created or it was uncoded as being insignificant. The level 2 review looked at the data set in its entirety to ascertain if the themes themselves *worked*, which, at that stage, they appeared to do. At the end of this phase, the data set provided a reasonably good idea of what the different themes were, how they fitted together, and the beginning of an overall story.

3.4.5.1.5 Phase Five: Defining and naming themes

This phase began once a satisfactory thematic map of the data was complete. A final *defining and refining* of the themes was then conducted to identify the *essence* of what the themes are about. This analysis to further refine the specifics of each theme, and the overall story the data tells generated clear definitions and names for each of the themes (Braun & Clarke, 2006).

3.4.5.1.6 Phase Six: Producing the report

Phase 6 commenced once a set of fully worked-out themes were finalised and involved a final opportunity for analysis prior to writing up the report.

3.5 Results

Thematic Analysis of the Focus Groups

Three reoccurring themes emerged during the thematic coding of the FG transcripts. The three themes identified were: flight training application, the ergonomic and virtual environment, and the perceived industry benefits of VRFS flight training. The FG discussions centred around these three themes, with comments falling into one or sometimes multiple themes.

Within each of the main themes, comments and discussion fell into two further sub-themes: positive and/or negative observations. As there was often overlap in what was considered by participants to be a positive and/or negative trait of a specific characteristic or function (i.e., one FI commented positively, while another negatively about the same phenomenon), both will be discussed in parallel in the Discussion section.

Figure 5 shows a graphical representation of the positive theme, while Figure 6 shows a graphical representation of the negative theme. Each illustration has been expanded to show the three reoccurring themes (outlined in red) of, flight training application, the ergonomic and virtual environment, and the perceived industry benefits that emerged. Then from each of these, the illustrations are further exploded to show the sub-themes that arose.

Figure 5

Mind-Map of Positive Commentary by Theme.

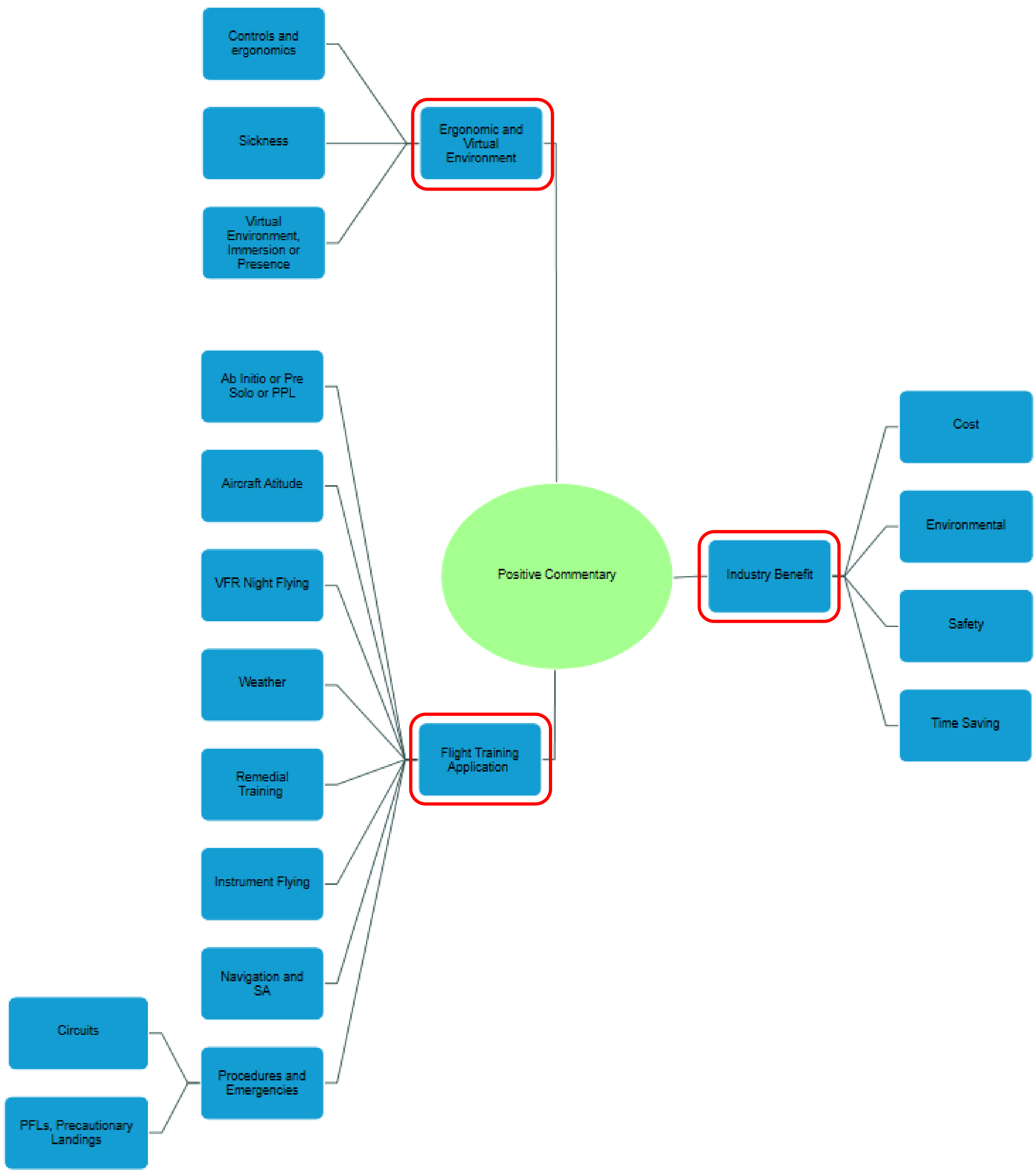
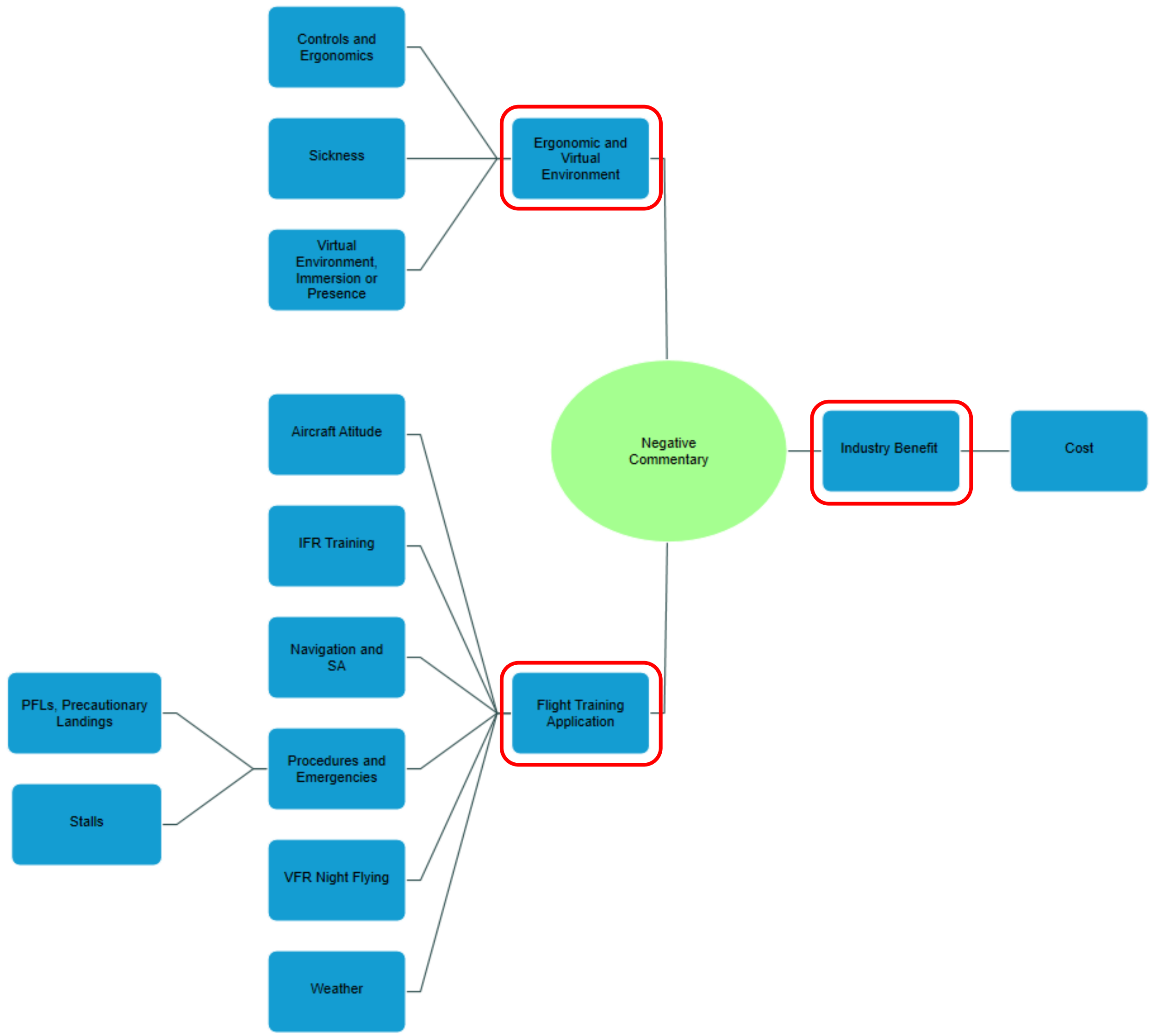


Figure 6

Mind-Map of Negative Commentary by Theme.



A word cloud (see Figure 7) was created using Nvivo to provide a visual representation in order to illustrate patterns of keywords and phrases that were used most frequently during the FG proceedings. To assist in highlighting more complex phrases and ideas a conversational filter was applied to the transcripts which filtered shorter words and phrases such as *like, right, ok* etc (Henderson et al., 2020). Although some detail may have been omitted by this process, it should be noted that word clouds do not provide context, instead, they emphasise only the frequency of words that have been used purely for visualisation purposes (Henderson et al., 2020).

Figure 7

Word Cloud: Showing the most frequently used words spoken by the FIs during the progress of the FGs.

In order to accurately relay the thoughts and opinions of the participants, verbatim dialogue was used in this section. As such, numerous excerpts are quoted directly from the FG transcripts to illustrate and provide thematic context of the discussion topic. Each comment is annotated [FI*n*, followed by A, B or C] (i.e., [FI6B] to indicate that comments were made by different participants and what grade of FI the contributor was).

Separating the descriptive phase and the interpretation phase of thematic analysis is also important (Patton, 2002), therefore analytical interpretation and discussion will be presented separately in the Discussion.

3.5.1 Flight Training Thematic Analysis

The first of the three themes to be discussed highlights the FIs thoughts and opinions regarding using the VRFS in flight training, and covers topics such as aircraft attitude, circuit training, emergencies and remedial training.

3.5.1.1 Aircraft Attitude

Instructors felt that when manoeuvring the aircraft (i.e., straight and level, climbing, descending or turning), that the aircraft's attitude, as presented by the VRFS, was an accurate reflection of that seen when in the actual aircraft during flight. There was general agreement that this would be useful, particularly during the early stages of flight training for teaching attitude flying and the circuit.

> *'the attitudes, everything was exactly the same. The glide approaches exactly the same.'* *[FI3B]*

'I found it effective. It was easy to do the manoeuvres required and to correctly set the other attitudes that we needed for climbs or glides or whatever.' *[FI4B]*

'the attitude, worked out really well, because I could do a normal circuit without actually looking at them [the flight instruments] again.' *[FI3B]*

'I would definitely use it as a tool, you know early on in the syllabus for circuit training and attitudes and that sort of thing.' *[FI2B]*

'You can see attitude, you can position yourself right' *[FI2B]*

'I think that it would be really good especially in those first stages in order to get them just the ideas of things like attitudes and stuff. Maybe they've been in an aeroplane a couple of times, they know what they're looking for and what it looks like. Then put them in [the VRFS] to learn all of the other basics—all of your lookout and attitude, instruments and all that kind of stuff. I think that would be very valuable.' *[FI4B]*

During the course of the FGs, a few of the FIs discussed the importance of making sure that the VRFS was configured/calibrated correctly. The concern being to ensure that the student *sees* what the *correct* attitude looks like, and doesn't unknowingly experience mislearning.

'Think it takes a little bit of calibrating. So when I was adjusted to where I said it looked right. Absolutely. Pretty much bang on.' *[FI2B]*

'It could be quite detrimental if they're [the student] practising it away from the attitude they're used to seeing in the aircraft.' *[FI8C]*

'But I think for a brand new student, and you ask them, right, how does it look when you're sitting in the aircraft? They're gonna go—I don't know, I don't really know what an attitude is, I don't really know what to look for. So I would hate for a student to get used to this fake attitude, and then going out in the plane and pitching it up way too high, and you know, end up climbing out at 60 knots, you know what I mean, because they're so used to it. That's one issue I can see.

[FI2B]

This wasn't considered significant by other FIs, as long as they felt that the principles were understood by the student.

'I don't think it needs to be spot on between the VR and the aircraft itself. I mean closer would be better, but once they have established the level attitude, it doesn't really matter. You tell them this is it. This is the level attitude and when it comes to turning, then they can just keep it the same which is the same technique as would be in any aircraft.' *[FI7A]*

'The attitude is different each day, anyway, in the number of different things.'

[FI9C]

You can show them the attitude as well. That's the same attitude for your turns. Even if it's not the perfect attitude you're going to see in the plane, you can get that basic principle. *[FI10C]*

3.5.1.2 Circuit and Approach

The FIs that took part in the study, on the whole, agreed that the VRFS would be beneficial when instructing students in circuit procedures and the approach to land. It was felt that as aerodromes are complex and busy environments that the VRFS could provide the student with an opportunity to learn the procedures associated with the aerodrome circuit in a less intense environment:

'It would be nice to be able to show them [the student] a circuit without having to worry about flying the aircraft or safety. These are the pictures. This is what it [the circuit] looks like.' *[FI8C]*

'So, for instance in circuit training, it would be really good for actually judging spacing, looking at the wingtip and whatnot, pitch, even for glide approaches, stuff of that nature.' *[FI6B]*

'You get them doing the checks and everything, and then you start talking about power, speed, profile. And you get them in the sim for an hour or two before doing the next flight, I think that would be huge.' *[FI3B]*

'So when I flew circuits in the simulator, it looked exactly like how I saw it in the plane.' *[FI5B]*

Observations were also made regarding the potential benefits of being able to manipulate the workload and level of risk the student experiences, for instance: the number of other aircraft in the circuit and the behaviour, type and amount of other traffic:

> *'I guess that's the beauty of it, you could choose how busy you wanted it [the circuit] to be because you still want them to experience that, such is life, like having to orbit and extend for everyone else because we had bottom tier or whatever. But then if you wanted to just do basics you can make it as basic as you want, which is a big plus.'* *[FI10C]*

> *'We actually want to offload some of the workload. Just get them to fly the circuit, you know, because initially, you might do the radio calls anyway. So, practice the actual pattern but in a less busy environment, probably be quite good as well.'* *[FI6B]*

> *'But then maybe that's the power of the sim, you can put people in the circuit to make it difficult for them. With the technology, you could even have AI traffic that do things wrong or something to put some scenarios in there.'* *[FI10C]*

The approach and landing were discussed. Of significance was the potential benefits of being able to easily and quickly reset/reconfigure the VRFS to enable instructors/students to repeat exercises, saving time, with minimal unforeseen disruption:

'When you're doing circuits and they [student] mess up an approach, and you have to wait until you're all the way back around the other side before you can show them the same thing.' *[FI9C]*

'You can set it [VRFS] up on final, having them really be able to look around and judge that profile, looking outside. Makes a huge difference. Absolutely!'

[FI8C]

'Same with the circuit situation, so you've got to go do it again. If they're losing it from 1000 feet, you just keep pulling them back to 1000 feet, rather than climbing out, spending 10 minutes getting back.' *[FI9C]*

'I agree, I took a glide approach this morning [in the VRFS] and it was quite good for looking at the wing to judge spacing.' *[FI6B]*

'Well, how many times have we been trying to teach the approach and then an ATR [ATR-72 passenger aircraft] *comes in, backtracks. You have to orbit or whatever, and you have to abort, what you're trying to teach.'*

[FI7A]

'And with the profile judgment for any landings, you can keep resetting it at different places and just play around with the close to the far. What does the runway look like? What is the runway shape? You can just keep reloading and loading and loading different scenarios.' *[FI1B]*

3.5.1.3 Forced Landing without Power and Precautionary Landings

Following on from the circuit and the approach, another similar topic emerged, the forced landing without power (PFL) and precautionary landing. The instructors felt the VRFS could benefit students in this area generally because in the VRFS they would be able to take the exercise to its conclusion (i.e., landing) which is not usually possible:

> *'You could do a full PFL, a real PFL to the ground.'*
> *[FI3B]*

> *'Definitely, so useful for PFLs and other emergency situations.'* *[FI4B]*

> *'That [the VRFS] could be really useful for teaching the student, as you're watching where they're looking. So for PFLs, you can actually see how much they're looking to the aim point and stuff.'* *[FI6B]*

> *'You can do the full intro to PFLs in the sim.'* *[FI3B]*

> *'You wouldn't have to say any of that [imaginary cloud or rain], you just do it, and that naturally meets precautionary landing after that, so you don't need to ask them or simulate anything, you just do it.'* *[FI7A]*

The ability to carry out exercises quickly and efficiently was identified, with the FIs discussing the benefits of being able to easily repeat exercises by dragging the simulated aircraft around the VE to any position and height as required:

'You can just drag them up [in the VRFS] to three-five [3500 ft] every time and say do a PFL.' *[FI3B]*

'Forced landings. I think forced landings would be pretty good, because again they're such long procedures, and you have to climb back up.' *[FI9C]*

Not all observations regarding PFLs and precautionary landings were positive. It was highlighted that a significant limitation, that restricts the VRFS in some aspects of training, is the pilots' inability to fully interact with the aircraft instrumentation:

'If you're talking about later-stage students doing PFLs, when you get into the full checks, you can't be on the MFD doing your trouble checks and stuff in the VR. At least not with the version I saw, potentially in future versions.' *[FI6B]*

3.5.1.4 Remedial Training

The FIs felt that given a student who is struggling to grasp the bigger concepts or needs more practice in specific areas of flight training that the VRFS could be useful:

'Ab initio, basic handling, remedial training, I think is where it's going to be huge.' *[FI3B]*

'I can think of several scenarios where I've had students who I think would already have benefited from what we can do in the VR, as it is.' *[FI4B]*

'Remedial training, visual attitude remedial training, is probably the biggest pro.' [FI2B]

'In terms of cost, it would save them [students] a hell of a lot if they could do the remedial training, a lot more of it, in the VR sim, helping out with some of those costs.' [FI1B]

Being able to easily and quickly repeat exercises, with the potential time and cost reduction benefits of this, were once again raised and noted as another potential advantage of using the VRFS for remedial training:

'Remedial training, just repeating from one point over and over again until they get it right, rather than spending 10 minutes trying to get back to that same spot. That'd be the main thing I think I'd use it for.' [FI9C]

'I think the value of repetition is something that's one of the major benefits, so you can choose to do it over and over again—anything that they're having trouble with.' [FI7A]

'A student recovered incorrectly five times in a row, no matter how many times I demoed it. It'd be cool to just stop it straight away, pause it back to safe, and you just have more time to slow it down and keep explaining.' [FI8C]

3.5.1.5 Ab-Initio Flight Training

The general consensus among the FIs was that VRFSs would be particularly beneficial in training ab initio/pre private pilot licence (PPL) students. Potential advantages such as simplifying procedures, reinforcing concepts and enabling independent student-centric learning were identified and discussed:

> *'I think it would be really beneficial in ab initio training, really early on, because you're not having to focus on the twist and scroll with the FMS or setting radios and stuff like that. It's actually looking outside, flying, setting and attitude, setting power.'* *[FI3B]*

> *'I think that it would be really useful for pre-solo because you can see where their eyes are looking when they're in the VR, from your instructor station. So you can see whether or not they're checking the right spacing and whether or not they're checking their centerline, whether or not they're checking speed etc. So all of those things where the student needs to be tailored into focusing on something specific. So I think it would be good for pre-solo, and yeah, pre PPL.'* *[FI4B]*

> *'I think there's a lot of value in it [the VRFS] for visual training.'* *[FI6B]*
>
> *'I think it's still a valuable resource that individuals can pick up. Definitely, to improve, you know, to be able to do things on their own time and also as a student. You don't need an instructor sitting there to move you on the screen, or you don't have to pause and get up and do that. If you're in there flying it by yourself. That kind of leads to a bit more independence.'* *[FI8C]*

'I think from a technology point of view. The new students are a lot more in touch with technology and new gizmo engagement, so I think that they will take to it a little bit better than someone who's a bit older.' *[FI7A]*

3.5.1.6 Other Training Areas

Additional to that already examined, the FIs also deliberated other areas of flight training during the course of the FGs where they felt the VRFS could benefit flight training. These topics covered basic instrument flying (IF), visual navigation, night flying, weather awareness and potential risk reduction.

3.6.1.6.1 Basic instrument flying:

Basic IF requires minimal interaction with cockpit instruments, therefore the FIs considered that the VRFS could be beneficial for training here as it provides an opportunity for students to practice their T-scan:

'under IF flying solely using the instruments, not to do with procedural stuff, then it will be very useful.'
'Yeah, especially as you can see where they're looking.' *[FI4B]*

'You can put them in cloud, get them on their VR simulator and do remedial training, T scans, you know what I mean.' *[FI2B]*

Overwhelmingly the FIs felt that the VRFS would not be useful in its current state for full instrument flight rules (IFR) training. This again was due to the pilots' inability to fully interact with the aircraft instrumentation whilst in the simulator:

> *'I can't really see it having that much benefit in terms of IFR procedures. Again then you're getting into, GPS load, verify, execute, monitor, you're getting into that tactile use of the avionics system, which I don't think you quite get from the VR.'*
>
> *[FI3B]*

> *'Less useful for procedural training such as IFR, we actually do need to see the buttons and stuff in front of you and program information. Trying to do that in VR, would be, imagine what the current technology would be, a little bit challenging. '*
>
> *[FI6B]*

3.5.1.6.2 Visual navigation:

Navigation is an important skill that students must master during the course of their training. Some of the instructors remarked on the potential advantages of being able to use the VRFS in this area for visual navigation, regional familiarisation and improving situational awareness:

> *'students are getting worse at navigating, even on some of the earlier on ones[flights], in places like the training area. Whilst it's definitely kind of more of a two-dimensional view of it, you could basically go on a tour, or as part of the start of training—this is where every town is and you can orbit over it for ages and none of that cost flight time. That can help them with their local situational awareness, lots, probably through that.'* *[FI8C]*

'You can, if the visuals were good enough, you could ever use it for visual navigation, like remedial loss procedures and stuff like that.' *[FI6B]*

'If they have trouble with situational awareness a lot of them do try to go in the other sim and try and figure out where things are, but it just doesn't give them the value. It gives them a little bit of value, but compared to VR where it can give you a reference and everything.' *[FI7A]*

'if you can get the topography and the terrain features to a really good level, you probably could use it for visual navigation. I think its main advantages will be in visual flight training.' *[FI6B]*

In contrast, some of the other FIs felt that it might not be that useful, or at least they wouldn't use the VRFS for this purpose:

I wouldn't really use VR for navigating. Navigating for me is ground prep. It's got nothing to do with your flying ability.' *[FI5B]*

'I wouldn't go use it for navigation flight.' *[FI8C]*

3.5.1.6.3 Night flying (including a component of IF):

Night flying in a single-engine piston aeroplane is considered a relatively high-risk activity. The FIs, aware of this, regarded the use of the VRFSs to be advantageous in enabling training and increasing skill, whilst also reducing exposure to the risk:

> *'night flying as well, because a lot of that is making sure that they're looking at the right instruments—your T scan etc. So I think it'd be useful in terms of, if they are not good at that stuff when they get to night flying, they could use that [VRFS] to refine their skills before you send them out into the night.'* *[FI4B]*

> *It would actually be huge for night flying. You think about how you judge your landing at night, using the peripheral vision, using the flare path lights, which you can't do on any other sim. So as you go past the runway, the edge of the runway. So I mean, it'd be huge for night flying, getting that judging the flare, setting an attitude, holding. I hadn't thought about that!'* *[FI3B]*

> *'Showing them what black hole effect is.'* *[FI1B]*

> *'As a pro for night flying, if you do a lot [VRFS sessions] you're reducing your exposure to night flying single-engine, in the actual aircraft, which is obviously quite a high risk. It's probably, maybe, one of the most high-risk operations that we do. So if you could do more of that in the sim, overall be a lot safer.'*
>
> *[FI6B]*

These observations were balanced with comments that highlighted potential issues with night flying training due to limited interactivity with the cockpit:

> *'Night flying. It might be quite hard with night flying because again there's a wee bit more that's inside, because you can't see outside so much. Bit more reference to your instruments and half of it's changing your brightnesses [on the instrument panel] and that sort of stuff. Think night flying might be a bit of a challenge.'*
>
> *[FI9C]*

3.5.1.6.4 Weather (poor and weather appreciation):

The ability to simulate different types of visual weather phenomenon was considered to be a positive attribute of the VRFS by the FIs. Manipulating the weather that the student actually sees, instead of having to *pretend or imagine,* was noted as a particular benefit:

> *'You could have a field day with it [VRFS], you can get through everything.'*
>
> *[FI10C]*

> *'I think you could very much so. How many times do we as instructors simulate that the cloud base has suddenly dropped, or they can't turn back, or there's a wall of cloud behind them? You wouldn't have to say any of that, you just do it, and there naturally meets precautionary landing after that. So you don't need to ask them or simulate anything you just do it.'* *[FI7A]*

'I think you could definitely make a lot of use of the weather you can simulate'

[FI8C]

'I did it in another sim [simulated 6km visibility], the student can't see anything— I know that place, but, I can't see anything. So doing it in VR, I would say that it could be quite real. You've just lost your field, pick another one. Do another timing run…' *[FI5B]*

Some FI's foresaw a potential issue with this however as they thought students might become desensitised, or overconfident in their abilities:

'Could have the potential to desensitise yourself to that bad weather if you're just doing it in the sim. I think that might be an issue.' *[FI6B]*

'And that makes you wonder how students are going to react to a, for example, a 600-foot cloud base in the VR, compared to how they're going to react in real life. I mean, some may just choose to do it because, well they can. They're not going to crash, they're going to die. Yeah, there could be a level of disconnect there or an issue in terms of saying oh well, my weather minima can be 600 feet now because I did it in the VR.' *[FI7A]*

'I think there's definitely a place for it in VR, but not all, replacing what you experienced in the aircraft. Stress levels you get in bad weather in the aircraft is gonna be a lot more stress than if you get into bad weather in the sim.'

[FI6B]

3.5.2 Virtual Environment and Simulator Hardware Thematic Analysis

The second significant theme that was identified during the coding process related to the VE and the physical simulator hardware. Comments coded to this theme include those discussing the computer graphical representation of the environment (i.e., the VE) that the simulator displays in the HMD. Also included were remarks regarding how *immersed* or *present* (i.e., how much the FIs felt they were actually *there*) while in the VRFS, as well as comments made about the physical controls for operating the virtual aircraft (i.e., control stick, rudder pedals and throttle controls).

3.5.2.1 VE and Presence

The FIs generally liked the VE representation presented by the VRFS with agreement that it was realistic and to scale, especially in comparison to other available simulators:

'It's really cool doing a circuit, you can look around, you can do good lookouts and you can see the instruments and that's all fine.' *[FI3B]*

'I thought it felt like 80% realistic.' *[FI2B]*

'It was impressive. I thought the graphics at high altitude, was really good.'

[FI7A]

'Especially compared to the other simulators. I mean one of them has pretty decent visuals, but I think, I think the VR might have been better.' *[FI6B]*

'It felt like you're in a real aircraft [experience of presence] because visuals are so accurate. The wing, you know, looking outside the aircraft that everything's to scale. Everything looks to scale, buildings, runway and everything. It's, it's almost completely realistic.' *[FI2B]*

Issues and concerns regarding the focus area of the HMD screens were raised. Some of the FIs found it particularly frustrating that they had to move their head, as opposed to just their eyes, when scanning and checking alignment to the runway:

'I keep my head in the centre, I use my eyes to do the scan. So I moved my eyes, as I said, then I had to move my head to each of the instruments. I thought it was a little bit, a little bit annoying.' *[FI2B]*

'Agreed, I found the same thing when I was trying to check my centerline and profile, looking at my attitude. Every time I flicked my eyes down to the airspeed indicator I couldn't really focus on it—I had to tilt my head down in order to focus on it properly. Then if you've got your head still there and you flick your eyes up to the centerline, then the air, the runway was out of focus. So I found that quite

frustrating and I can imagine that that lack of focus would probably give me a headache after an amount of time. I think because my eyes are constantly trying to refocus.' *[FI4B]*

'So your, the, focus areas just needs to be wider.' *[FI5B]*

'when you're trying to have one eye forward to look at the runway and one is down at the PFD, and what's your altitude. Your eyes are flicking up and down all the time it's not your whole head.' *[FI1B]*

3.5.2.2 Hardware/Controls

Significantly very few positive comments were made regarding the control hardware. Here the FIs overwhelming felt that the lack of feedback through the controls presented a major issue to the overall effectiveness of the VRFS:

'My only concern with it would be around its implementation through tactile use.' *[FI3B]*

'Definitely the feel thing. That's a major I think because definitely when we were having a play, I found that the feel, ultimately control....' *[FI4B]*

Tactile or the actual like force feedback.' *[FI1B]*

'Force feedback of the actual controls for them [the student]. When you're looking out, for example, and you don't feel that feedback on the control column could be a barrier for it.' *[FI4B]*

'The only thing I found was the feedback wasn't quite there when you're trying to flare. I was trying to put in [control]*, almost over-rotating.'* *[FI3B]*

'It needs to have good force feedback as well for high G manoeuvres, so you can actually feel that the stick feels the same as it does in the aircraft.' *[FI6B]*

'then there's the physical feel side of it that's limiting everything right. The actual VR sim would be such a useful tool.' *[FI2B]*

'That tactile feel—it just wasn't quite right.' *[FI3B]*

'I don't know if that's just a limitation with current technology as well but I also noticed that there was a lot of lag with control inputs, and especially like the throttle. It could just be a software patch or something, or different hardware but that was my experience a little, a lot less responsive than a real aircraft '

[FI6B]

In addition, the fact that the VRFS is a fixed base simulator (i.e., it doesn't move during flight) also drew some criticism:

'the fact that there's no movement, there are no bumps, you can't feel the vibration of the engine, you know, that sort of thing.' *[FI2B]*

'My only issue with it is if you don't know where your hands are, once you've got your hands on a stick, on the throttle. It's knowing where to then put your hand to control other things.' *[FI3B]*

3.5.3 Perceived Benefit and Drawbacks Thematic Analysis

The third and final theme that was identified during coding was that of the FIs opinions and attitudes regarding the perceived benefits and/or drawbacks that the VRFS might provide to the flight training industry. Topics that were coded to this theme covered areas such as flight safety, the cost of flight training, potential time saving, environmental impact considerations and simulator sickness.

3.5.3.1 Safety

Agreement was ubiquitous amongst the FIs concerning the potential safety benefits of using VRFSs to undertake certain aspects of flight training, in particular, night flying and other high-risk activities:

'Night flying. If you do a lot in the Sim you're reducing your exposure to night flying single engine in the actual aircraft, which is obviously quite a high-risk operation. Maybe one of the most high-risk operations. So if you could do more of that in the sim, overall it'd be a lot safe.' *[FI6B]*

'For any sort of, not unsafe, but the high-risk stuff that you do, you could spend 20 hours doing it in the VR and not expose yourself to that risk, which certainly, probably, has its advantages.' *[FI10C]*

'It can make things a lot more real than the current stuff [simulators], current technology, that we have. Some of this new VR stuff, even though there might be a bit of a disconnect, it still can make it as real as we can get it without actually being in a really bad situation.' *[FI10C]*

3.5.3.2 Cost

The VRFSs capacity to reduce the overall cost of flight training for the student and operator were examined by the FIs. The general consensus being that potentially it could, particularly in the area of remedial training, where time and thus financial burden could be reduced.

'Electricity is cheaper than Avgas.' *[FI1B]*

'Reduces cost for them [the student] too if it is remedials [addition remedial lessons] as well, makes the course cheaper.' *[FI1B]*

'For example, you could get rid of two airframes potentially. So, in terms of space on the apron, cost, I mean, it comes back to cost again but you're not having to lease the space and once again landing fees and all the other stuff.' *[FI7A]*

'In terms of cost, it would save them [the student] a hell of a lot if they could do a lot of the remedial training in the VR sim—helping out with some of those costs.'

[FI1B]

Remove that pressure, pressure of saying we've got to get back now and we're running out of money, running out of time, fuel.' *[FI7A]*

'So less money spent on remedial training on the aircraft for the student, less time by the instructor focusing on them, less money from the company having to allow them to use an asset to do the remedial training.' *[FI1B]*

Although one FI did point out that VRFS might potentially be an addition to the simulators already owned by an FTO, and therefore could actually result in an increase in expenditure.

'I see the benefit with regards to all the stuff we're talking about and the ab initio training and so on, but I can't see it replacing any of the other sims we have. The other sims all have their place. So it would still be an additional cost.'

[FI3B]

3.5.3.3 Time Saving

Time-saving aligns hand-in-glove with other benefits. Thus some of these points here have been touched upon in other sections specifically related to a training benefit, noting time-saving only as a by-product of the perceived main benefit. They are mentioned here as the potential to save time in flight training should not be overlooked:

'The sims run cheaper, which potentially frees up assets for other people to get through the course quicker, which means you get more people through faster.'

[FI1B]

'You don't need to waste time going to and from the aerodrome when that isn't the focus. To go do a remedial fight and practice some more PFLs, ah, but the cloud

base is 1000 feet, ah, it's 1500, ah, it's 2000, oh it's back down to 1500, and so you spend the next two weeks waiting for a weather gap to go up and practice a PFL from 2500 feet. Whereas you can chuck them in the [VRFS] sim straight away and do it all.' *[FI3B]*

'We were waiting for the perfect conditions, and then the circuit was busy and then, you know, we were orbiting for half that lesson and that sort of thing. So, in terms of cutting down hours and costs, it would definitely for remedial—100%.' *[FI2B]*

'I think that you could definitely cut down on some of the flights that we do if they [the student] were to a really good standard in their handling and such—due to the fact that they had done a lot of stuff in the VR.' *[FI4B]*

'Also time as well, with time in the cockpit, time walking to the cockpit, getting fuel. All the other types of time-related costs. More than one person involved as well, and running an aeroplane maintenance time. That's just the top of my head.' *[FI7A]*

'More real, more beneficial.' *[FI9C]*

'Better use of your time as a student.' *[FI8C]*

3.5.3.4 Environmental

Naturally, in today's climate of environmental awareness and responsibility, the FIs touched on the subject of flight training and its contribution to the overall environmental impact of the aviation industry. It was suggested that the VRFS could potentially be used to reduce emissions in flight training.

> *'I think it's a huge point in today's world, with everybody getting on board with reducing emissions, co2 emissions, so I didn't, I didn't think of that, but I think that's a major point. Nowadays, compared to five years ago.'* *[FI7A]*

> *'Reducing maintenance and things. Looking really abstract you could even argue it reduces the environmental impact of flight training if we then have less aircraft in the air, you know, less congestion, less exhaust gas, all that sort of stuff.'* *[FI10C]*

> *'So, going back to the greenhouse gas topic, because it's quite a big topic, I think compared to a basic simulator where you don't have the VR aspect. Probably the carbon emissions will be the same. More or less.'* *[FI7A]*

3.5.3.5 Sickness

Mixed observations were recorded regarding experiences of simulator sickness during exposure to the VRFS, with one FI reporting an increase in feelings of sickness compared to other sims, whereas another stated reduced effect.

> *'Probably one thing I don't like—I couldn't see my body. That's what made me sick, because I would look down and find my legs, and then, where are my hands, and so I'm reaching to try and find something. So that's probably one of the reasons why I got sick as well. Obviously, with technology improving you should be able to see your body at some point.'* *[FI5B]*

> *'One of the things I found quite interesting about it, I don't know if anyone else found, is I felt so much less sick in the VR sim. I get really, really motion sick in the other simulator and I don't know what it is, but, yeah, for some reason didn't. So that was quite nice, just as a student would.'* *[FI8C]*

> *'I had the opposite. I couldn't look at the wing whilst I was feeling like I'm gonna throw up, so I had to just look straight ahead. For me, it was like my body wasn't feeling what my eyes were seeing. So you'd have to put on a suit that increases the pressure or does things as you make.'* *[FI5B]*

3.6 Discussion

3.6.1 The Research Problem

Virtual Reality is an emerging technology, although its use is becoming more widespread. Given the technological advancements in modern computing power, VRFSs may be able to offer a viable addition or adjunct to the methods traditionally employed by FTOs, primarily due to their cost advantage. As discussed in Chapter Two, outside of the US military, existing research, particularly from civil FTOs, appears limited in scale and number, with few studies from the civil sector focusing on flight training.

Several themes emerged during the thematic analysis of the data from the two FGs. In the discussion that follows, these themes are categorised as being either disadvantageous/negative (generally not supportive of using xR) or advantageous/positive (generally in favour of using xR). It should be noted that the categorical classification of themes as *disadvantageous/advantageous* or *positive/negative* was purely based on a subjective interpretation.

3.6.2 Potential Disadvantages

During the FGs several key issues were discussed that the FIs felt would limit the contribution of VRFSs in their ability to deliver effective training, and/or may even create issues for students further along the training pipeline. The significant areas of concern focused on the topics of; feelings of a break in presence, IFR training: desensitisation and overconfidence; and the HMD resolution.

3.6.2.1 Break in presence

The FIs expressed concerns about feelings of a break in presence (BIP), or being *disconnected* (as described by them) from the VE, whilst immersed in the VRFS. These observations were manifest mostly as a result of:

- not being able to see their hands/body,
- experiencing no *feedback through the flight controls,*

These effects have the potential to cause a break in presence, which is described as a feeling of being there within the VE (Slater, 2018) and can lead to a reduction in the overall effectiveness of the training being undertaken (Stevens & Kincaid, 2015). Unfortunately, nothing can be done in VR to overcome the inability of the user to see their own physical body as the eyes are completely encompassed in the HMD. A potential solution to overcome this would be to use MR which offers the user the ability to view one's real body through the display of the HMD. Alternatively, through the use of hand and body tracking technology (UltraLeap, 2021), an avatar (i.e., a virtual representation) of the user can be displayed within the VE which might resolve the issue of not being able to see a physical body. This solution must be supported by the simulation software manufacturer which is not the case with many flight simulator providers and necessitating the requirement for expensive bespoke software.

The FIs also indicated that the lack of feel whilst flying the VRFS was a significant issue and very different to what they and the student would experience in the real aircraft. As mentioned, the VRFS used in this study was a prototype that employed COTS gaming flight controls with no force feedback capability. The technology to provide force feedback through the various flight controls is available but varies greatly in complexity and cost. Using more sophisticated flight control hardware may improve the effectiveness of the VRFS and potentially produce an overall better product, but the drawback of this option comes in the form of additional cost, complexity and operator knowledge. Elevating the cost and expertise required to purchase and operate VR simulators may push them beyond the capability of smaller FTOs, rendering mute the potential benefits this type of simulator technology might offer.

3.6.2.2 IFR Training

Conducting a flight under Instrument Flight Rules (IFR) is procedural, requiring a great deal of interaction with, and manipulation of, the flight control systems (i.e., autopilot) and the navigation systems (i.e., Garmin G1000 GPS). As this constant interaction (e.g., *pushing buttons, turning dials and actuating switches etc)* is a requirement of this type of operation the FIs felt that the lack of intractability offered by VRFSs would be able to provide minimal benefit to the training of students in this area.

This issue is similar to that of feeling disconnected, discussed above, and could potentially be solved in a similar way. MR would allow pilots to see a full instrument display panel. There would, however, be a requirement for this real-world hardware to be fully integrated and synchronised with what is displayed in the VE, this is a complex undertaking. The option to use an avatar to manipulate VE buttons, dials and switches is also problematic. In this instance, the physical and virtual artefacts would need to be precisely aligned and again full synchronisation would need to exist between the software and hardware, as seen in the VRM simulator recently certified by EASA in Switzerland (EASA, 2021; Riesen, 2021). Both of these solutions, though achievable, would again increase the cost and complexity of the VRFS.

3.6.2.3 Desensitisation and Overconfidence

FIs felt that the VRFS could increase training risk by introducing desensitisation and overconfidence in students. It was felt that if a student thought they could achieve an outcome in the simulator, some might assume they then had the skills and experience necessary to reproduce the same results in reality. Flight simulators have been in use in civil and military aviation for over 100 years, and have a demonstrated record of reducing the risk and improving flight safety in training and operational environments (Masson, 2021; Taylor et al., 2003).

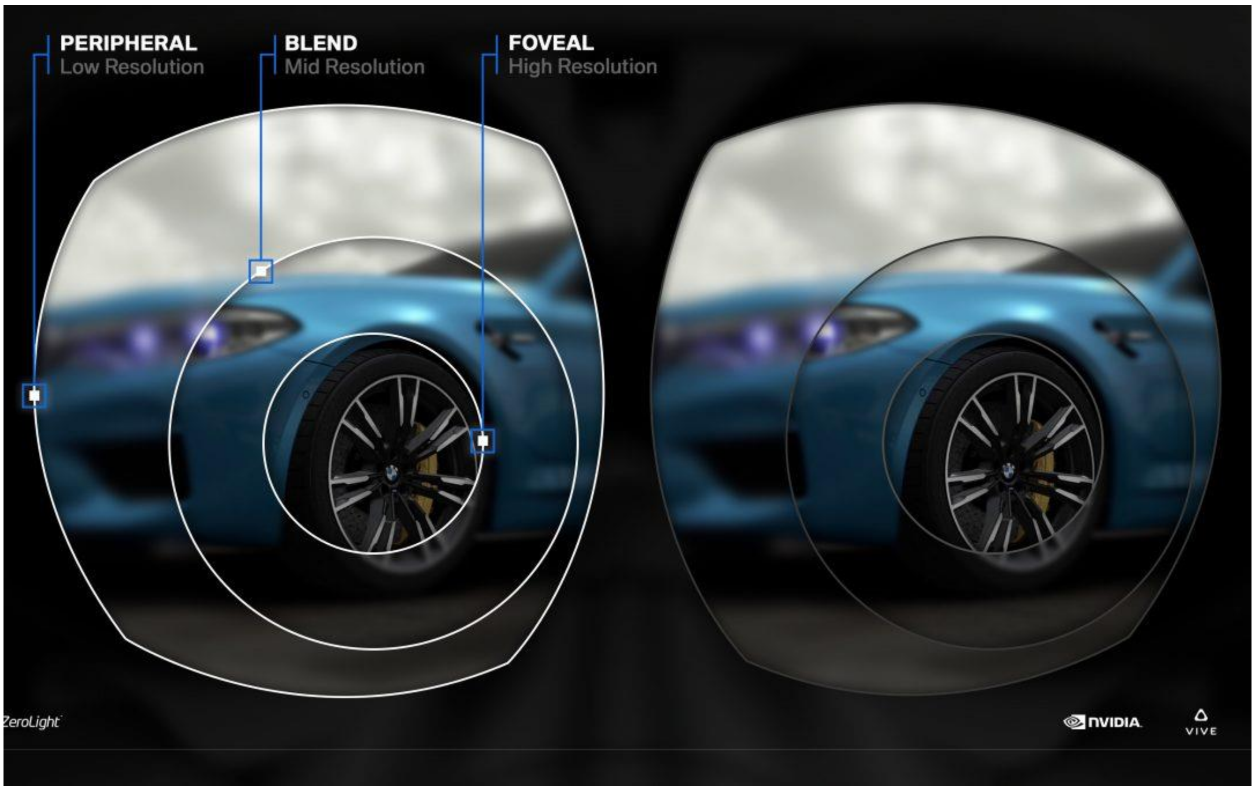
This concern was legitimate and therefore students should continue to be closely and continually monitored throughout the flight training process by their FI whose responsibility it is to guide students and if necessary report and curtail this type of risk mindset. It should also be remembered that flight simulators are an aid to facilitate flight training and not a substitute for the experience gained through flying a real aircraft in the natural environment (Tolin, 1986).

3.6.2.4 The HMD Resolution

Although the FIs were generally complimentary regarding the quality of the VE, there were particular idiosyncrasies of the HMD adopted for the study that were deemed distracting and detrimental to the overall effectiveness of the VRFS. Specifically, there was an area of the HMD screens that was noticeably more in focus than the surrounding display area. This area of fixed foveated rendering (see Figure 8) meant that if the user moved their gaze (i.e., just their eyes) away from the centre of the display, there was a noticeable reported degradation in image quality/sharpness (Sag, 2020).

Figure 8

An illustration of foveated rendering (high resolution) in the HMD display. Note the difference in detail between the area depicted within and without the boundaries of the foveated rendering. Source: O'Connor (2019). How Zerolight uses foveated rendering in enterprise VR. Academy of International Extended Reality.



This design feature could be overcome by keeping one's eyes fixed and moving the head around to look at different objects. The problem with this is that in some phases of flight (i.e., approach to land) pilots typically keep their heads still, looking down the runway to their landing point, and only briefly gaze down (moving the eyes only) to check instruments. The FIs identified that having to move the head instead of just the eyes could cause eye strain and headaches, and was unnatural in comparison to typical behaviour.

HMD technology and the resolution of the screens contained within are continually updating and improving. This has resulted in some manufacturers moving away from fixed foveated rendered areas because they can produce resolutions of high enough quality across the whole screen, or with gaze, detection move the rendered area in concert with the eyes (DecaGear, 2021; HP, 2021).

3.6.3 Potential Advantages

When considering the data gathered during the FGs in their entirety, comments made by the FIs were more positively tilted. The FIs felt that the VRFS offered unique capabilities which they could use to improve the training experience of their student. Several key areas were identified by the FIs as positive attributes or characteristics of the VRFS that it was believed could benefit training and student progress.

3.6.3.1 Visual Flight and Aircraft Attitude

One of the advantages identified by the FIs was the VRFSs ability to aid in the teaching of *attitude* flying. Aircraft attitude is the relationship between the position of an aeroplane relative to the horizon, where the horizon is defined as the point at which the sky meets the sea (CAA NZ, 2021; FAA, 2014). Learning the correct *attitude* of an aircraft in flight is fundamental if a pilot is to manoeuvre an aircraft correctly during flight (CAA NZ, 2021; FAA, 2014). The FIs found that the VE and virtual aircraft, when set up correctly, offered the ability to demonstrate and teach the correct aircraft attitude during different phases of flight which was considered a significant training aid.

3.6.3.2 Cost and Time-Saving

The FIs felt that having the ability to continually repeat certain exercises, manoeuvres or phases of flight was a particularly powerful and useful capability of the VRFS. They believed this could lead to cost savings and time reductions in the training pipeline, as also suggested by Pope (2019) and Sheets & Elmore (2018).

One area identified by the FIs where the VRFS could be used was as an aid to circuit training. The circuit[7], as defined by CAA NZ (2021), "…is an orderly pattern used to position the aeroplane for landing and minimise the risk of collision with other aircraft." The ability for a student to practice the circuit pattern, or be positioned at any point therein, time and again, so they can repeatedly practise any of the phases of flight, has the potential to contribute significant reductions in learning time (Sheets & Elmore, 2018), operational time and costs (Pope, 2019).

This capability could also be useful in PFL, precautionary landing and other emergency procedure training (Lewis & Livingston, 2018; McCoy-Fisher et al., 2019), all of which typically requires a lot of repletion by the student in order to perfect and is again time-consuming. As opposed to practising in a real aircraft, initial and/or ongoing training could be conducted in the VRFS to enable a student to become familiar with these procedures and thus potentially saving time in the aircraft (McCoy-Fisher et al., 2019).

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[7] The circuit is a procedure that aircraft follow around an airfield—akin to an oblong race circuit in the air. Usually all turns in the circuit are made to the left and aircraft in the circuit fly at a height of 1000 feet above the airfield. The circuit is used primarily for the safe flow of arriving and departing air traffic to an airfield.

Also identified was the opportunity presented by the VRFS to conduct remedial training (i.e., a re-fly, the need to repeat lessons due to not meeting the required standards). Here again, it was thought that VRFSs also have the potential to save time and costs, enabling students to not only practice in areas that need improvement but to do so with or without an instructor, in their own time, with less pressure (Pope, 2019). Also suggested by McCoy-Fisher et al (2019) was the use of the VRFS in training could reduce the instances of remedial training in the first place.

3.6.3.3 Reduced Risk

There is a risk associated with all flying. Using simulators reduces this risk, particularly in flight training (Masson, 2021). VRFSs have the potential to reduce pilot exposure to risk whilst importantly still delivering high-quality training (Pope, 2019). The FIs acknowledged that a combination of the realistic VE and the capabilities of the VRFS would be beneficial in delivering training in the operations associated with the higher risk operations conducted at the FTO, in particular: night flying, low flying, terrain & weather awareness.

3.6.3.4 Environmental Impact Reduction

Some of the environmental benefits of using VRFSs instead of real aircraft include lower fuel emissions, a reduced carbon footprint, zero noise pollution and a reduced impact on the local area, particularly at night (Lawrynczyk, 2018; Masson, 2021). The FIs were cognisant of the perceived negative impact of their industry on the environment. They considered the ability of the VRFS to assist in reducing this impact to be a significant positive in favour of adopting this technology.

3.6.3.5 Presence

Presence is often used as an indicator of the environmental soundness of VR and VEs. It is generally regarded as an essential condition for the transfer of skills and knowledge (i.e., training) to real-world situations (Mestre, 2006; Regenbrecht et al., 1998). When comparing their experience to that of the legacy simulators they use, there was general agreement that the FIs felt *within* the simulation. Having the ability to look all around them and see familiar local features added to the general experience, an experience they thought students would potentially benefit from during training.

3.6.4 Limitations

This study was conducted with the assistance of a small convenience sample of participants from a large (for the originating location of the study) FTO. As a consequence, there are limitations in the ability of the results to be generalised to other FTOs, or the wider aviation community. While the nature of the pros and cons identified in the study could be unique to the FTO it is suggested that they are likely similar in nature to those generally experienced by FTOs conducting flight training globally.

The senior management, in particular the CEO and CFI, of the FTO were helpful and understanding from the outset of this study, facilitating access to their highly qualified, experienced, and busy FIs, from which the ten participants were selected. Every effort was made to avoid wasting participant time, even so, the period absorbed by each FI during the various stages of the FGs amounted to in excess of two hours. Data from a larger participant population would have been preferred, however, the negative operational and business disruptions to the FTO would have been significant, and was therefore not possible at the time of this study.

A further limitation was that the study used a *hand-built* prototype VRFS which was developed as part of a proof-of-concept project and not specifically designed for training. During the preparation for the FGs, each of the FIs had the opportunity to experience flying the VRFS. Unfortunately, again due to time and operational constraints, this exposure was short (e.g., 10–15 minutes max). The VRFS used low-cost COTS flight controls, with no force feedback, some of which were mounted in/on a wooden box, constructed for the purpose. The VRFS controls could not then be configured to accurately replicate the feel of the flight controls that the FIs would be used to. The VRFS seat was fabricated from an old motor racing seat reclaimed from another simulator project, which was mounted on a cut-down office-chair frame and secured to a wooden base (see Figure 4). The prototype's switches, knobs and dials were either not there or physically located in a different place than that found in the aircraft. The HMD, although relatively new, had been overtaken, technologically speaking, in the marketplace, and even superseded by its own manufacturer. It is conceivable that the combination of these factors may have degraded the overall experience of the FIs as there was insufficient time for them to acclimatise to the VE and the physical feel and idiosyncrasies of the simulator.

Further to the remark above. Participants subjectively interpret the same *experience* in different ways (e.g., differing levels of presence) (Matthews, 2019). A VR system will always offer the same level of immersion, but the level of presence may differ depending on a user's psychological response to the simulation and the distracting or unfamiliar nature of the real physical environment they are situated in (Dalladaku et al., 2020). Early-onset cyber/simulator sickness, or simply feelings of *queasiness*, may also impact user experience. More time perhaps should have been allowed for participants of the FGs to become fully (or at least more) accustomed to what potentially was their first experience in VR (almost certainly in a VRFS). Doing so might have provided different experiential responses to research questions.

3.6.5 Conclusion of the Focus Group Study

It has been suggested that there are some areas where the FIs felt that VRFSs could successfully be deployed in civil flight training: and where deployed, may present an opportunity for civil FTOs to make improvements in time, cost, safety and environmental impact. These findings are in line with those of Pope (2019), Sheets & Elmore (2018) and Lawrynczyk (2018).

The FIs identified several distinct potential drawbacks regarding the use of VRFSs in a training context, as they stand currently. Not least, limitations on cockpit interaction, control feedback and feelings of a break in presence were singled out for criticism on several occasions. It would be remiss not to note though that hardware and software technology is already making significant advancements in this area. With the introduction of MR, accurate hand tracking and force feedback systems for instance already available as potential solutions to these specific issues (Brunner, 2021; UltraLeap, 2021; Varjo, 2021).

There were, conversely, a number of potential advantages to using VRFSs that emerged from the FGs. Noteworthy among these was the possible capability of VRFSs to save time, decrease costs, reduce risk and lower the negative environmental impact of flight training. Many of the perceived potential benefits identified by the FIs were similar to and in line with those suggested in a number of the published studies identified in the ScR, such as Dalladaku et al. (2020), Lawrynczyk (2018), Lewis and Livingston (2018), Pennington et al. (2019), Pope (2019) and (Sheets & Elmore, 2018)

Based on the above and within the context of the methods and techniques already employed in simulator flight training, it is suggested that VRFSs are at a stage where they could realistically be considered an addition to (but still not yet a replacement for) the other type-specific flight simulators/actual aircraft presently in use (Tolin, 1986). Used in concert with current technology and practices, VRFSs can potentially offer real benefits to the flight training industry. It is important to remain mindful of their limitations and therefore, at this stage, as also suggested by Lawrynczyk (2018), should not be considered a fix-all or alternative solution for every flight training eventuality.

Following on from this study there is an opportunity for further research using VRFSs in a flight training context at civil FTOs. Specifically, a replication study could be undertaken with a similarly qualified group of FIs using professional grade flight control hardware (i.e., with force feedback) in concert with more up-to-date HMD technology (i.e., higher resolution, wider foveated rendering area, etc.). Accademia, in association with an FTO, could also conduct a quasi-experimental[8] study on student pilot participants to ascertain if there are significant differences in performance between students exposed to VRFSs and those that are not.

From a practical perspective, there is little reason why FTOs with the right technical skills/experience couldn't begin to adopt VRFSs as part of their simulator solution now as there

[8] Due to the nature of the aviation population, (i.e., limited number, age, gender, qualifications and experience) it would be difficult to conduct a true experiment where participants were randomly assigned to groups.

already exists data to suggest that this technology has the potential to benefit student pilots undergoing flight training.

Chapter Four: General Discussion

Despite the global downturn in the aviation industry post-COVID-19, it is predicted that the aviation industry will still experience the effects of a significant shortage of skilled and qualified, pilots in the near future (ICAO, n.d). This shortfall appears to be, at least in part, due to insufficient training capacity to meet the demand, compounded by outdated learning methodologies and the inaccessibility of affordable flight training to prospective candidates (ICAO, n.d). To meet the predicted demand for approximately 763,000 new pilots by 2039, FTOs around the world will need to consider new, time and cost-efficient technologies for use in pilot training (Boeing, 2020).

The aim of this thesis was to answer the following questions:

(RQ1) *What is the nature of the evidence to support the use of extended reality (xR) flight simulators in traditional flight training methods?*

(RQ2) *What are the opinions of professional civilian flight instructors toward using virtual reality flight simulators as an adjunct to traditional flight training methods?*

In order to assemble the data necessary to answer these questions two studies were carried out 1) An ScR of the existing literature and 2) An FG study involving participants that were civilian flight instructors.

4.1 Scoping Review

Despite significant innovation and investment in xR technology (Alsop, 2021) only 18 studies were identified that were deemed to be relevant to RQ1. Reasons for the scantness of published studies in this field could be attributed to the relatively new area of research, or that work is yet to be undertaken, or is presently in the process of being produced but not yet publicly available. In support of this, of the 18 papers included in this study, all were published within the last three years (i.e., since 2018). The evidence that does exist supports the notion that xR could be used successfully as an enhancement to existing, traditional, methods for pilot training. Those studies also suggest that participants that undergo flight training using xR technology are at least as good as those trained using traditional means, with flight training taking less time, at a lower cost with reduced environmental impact (Dalladaku et al., 2020; Pope, 2019; Sakib et al., 2020).

Almost half of the studies were carried out by the US military (e.g., U.S.Air Force, U.S.Navy and U.S.Army), who are also experiencing pilot recruitment and training pipeline throughput issues. Unlike civil aviation, it would appear from the evidence that these organisations have the time, resources and, most importantly, the desire to investigate alternative solutions to their pilot training problem (Dalladaku et al., 2020; Lewis & Livingston, 2018; McCoy-Fisher et al., 2019; Pons, 2018). The remaining studies mostly concentrated on nuanced areas of aviation (i.e., human factors and machine learning) with little research specifically looking at civil flight training in an FTO environment.

As is common with new solutions, technological or otherwise, pros and cons with the implementation and ongoing use are par for the course. XR VRFSs are no different, with the pros and cons of the technology being acknowledged in both the published literature and the FG data.

4.2 Focus Groups

The FGs identified several *positive* characteristics that suggest the existence of further evidence in support of the use of VRFSs in flight training. Noteworthy among them was the potential to teach attitude flying, make reductions in time and cost, the ability to lower risk, and limit the environmental impact of the flight training industry. These observations are in line with those made by Pennington et al (2019), Pope (2019), Dalladaku et al. (2020) and Lawrynczyk (2018).

As no one solution typically provides all the answers, it was unsurprising that the ScR and FGs identified areas where xR flight training had limitations. One of the most significant of these limitations is that of a Break in Presence (BIP) in the VRFS. This limitation is particularly problematic if the pilot is required to engage with certain aspects of the physical cockpit environment/equipment (e.g., buttons, dials and switches etc.) (Laptaned et al., 2019; Lawrynczyk, 2018; Oberhauser et al., 2018). For this reason, the FIs who took part in the FGs further noted that VRFSs (in its current configuration) would be limited in its usefulness when teaching full IFR. Hand/body tracking and avatars could potentially alleviate this issue, although the simulator software needs to be compatible (UltraLeap, 2021). MR has the potential to overcome this limitation as it develops in sophistication (Dalladaku et al., 2020; Howard, 2019; Varjo, 2021), as does the mapping of physical hardware to the VE seen in the world's first certified VRFS (EASA, 2021; Riesen, 2021).

Of some concern to the FIs was that some student pilots might become overconfident or even desensitised to risk if overexposed to VRFSs. Although this is potentially a legitimate concern, it is not a new one and not unique to VRFSs. Flight simulators do though have a long and well-documented history of success in flight training (Masson, 2021; Taylor et al., 2003). However, flight training in simulators is open to abuse—for this reason—simulator training should be purposeful and monitored. It is an FIs responsibility to guide students in all aspects of their training and if it becomes necessary report/curtail risk-taking behaviour if it is observed or suspected.

4.3 Limitations

Due to the very specific nature of aviation flight training and the relatively small population size therein, the generalisability of this study and others like it is limited. Study populations will, as was the case in this FG study, typically have to consist of convenience sampled participants selected from a specific population (e.g., student and qualified pilots). Some of the eligible studies included in this paper selected participants from the general (i.e., non-aviation) population. It is argued that individuals who are potentially not interested in operating aircraft and that haven't developed or possess the specific skills (e.g., hand-eye coordination) make poor subjects upon which to base the potential efficacy of aviation training devices.

As has been noted previously, the majority of the published data on the use of xR technologies in flight training has been conducted and published by the military. Military flight training is conducted in a very different manner, with equally differing objectives, to that of civil flight training. Although this is potentially generally useful, the data is not immediately transferable from a military to a civilian context. As such this study has contributed and represents only a small data set toward researching the civil applications of xR technology in flight training, which is an area that it is suggested requires a great deal more attention from the civil sector.

4.4 Future Research

Transfer of training (ToT) is a learner's ability to transfer the knowledge and skills learned in a training session to an actual application (U.S. Office Of Personnel Management, n.d.). Recent research by Cooper et al. (2021) and Likens and Eckert (2021) suggest that by using xR, ToT, including information retention and execution confidence, can potentially be increased significantly. The ToT effect from VRFSs to the real aircraft environment is an under-researched topic, therefore, research in this area could be conducted to gather data to assist in establishing the suitability of the technology in (civil) flight training.

With the exception of one US military study (only involving military participants, n = 966), none of the other eligible studies involved large population groups. Considerations should be given to conducting longitudinal research on a larger scale in the future involving civilian pilots to establish ToT and effectiveness over time.

There is also a research opportunity for a comparative study to be conducted to establish if there is any advantage in using force feedback as opposed to non-force feedback controls. As it could be argued that one of the advantages of VRFSs is the relative low cost of the simulator when compared to the alternative (e.g., traditional simulator or aircraft), the question: *is there a tangible need to go to the extra cost of purchasing force feedback hardware*? could benefit from further investigation. In line with this suggestion, additional research could be undertaken to establish a comparison between VRFSs and FFSs. This has the potential to save organisations millions of dollars if there is evidence to suggest that there is little perceptible difference between the two.

Gaining the general acceptance and subsequent certification of the aviation regulatory authorities should be an area of focus for researchers and industry when considering the widespread adoption of xR orientated flight training technology. For the technology to be adopted and trusted en masse by these organisations (e.g., CAA, FAA, EASA, CASA etc.), and therefore used most effectively in flight training, more testing, development and standardisation is needed. It might be suggested then that the civilian flight training industry is watching closely the costly and time-consuming experimentations of the US military, allowing them to test and refine the technology before committing to it themselves. The certification of the world's first VRFS by EASA, manufactured by VRM Switzerland (EASA, 2021; Riesen, 2021), has demonstrated that not all civilian FTOs and associated technology companies are content to just observe from a distance. Industry news and press releases indicate more companies are joining the movement toward more modern approaches to training. It could be suggested then, that now would be a good time for the academic and the FTO community to partner and ensure the products potentially adopted by FTOs in the future are fit for purpose and capable of delivering efficient, effective training at a lower cost to the benefit of students and the environment.

4.5 Conclusion

This thesis combines two studies and contributes to the existing, albeit limited, body of research that exists on the topic of xR technology (i.e., VRFSs) applications in a flight training context. More specifically, this thesis has for the first time, provided insight into the attitudes of flight instructors from a large civil FTO toward the potential benefits offered by VRFSs in civil flight training.

Despite the looming pilot shortage, reported by the aviation industry itself (Boeing, 2020; ICAO, n.d) and the negative impact the aviation sector is having on the environment (ICAO, 2021), it is mystifying to see that on the surface little appears to be being done by civil aviation to investigate these new, cheaper, cleaner options for training the next generation of aviators. It might be suggested that this perceived hesitancy to innovate is a result of a reluctance to change, suspicion toward new technology, organisational inertia, or the fear of a reduction in revenue (due to potentially cheaper training methods), all of which can lead to negative consequences for the industry (Moradi et al., 2021).

The studies here suggest that, what research has been published, presents both pros and cons regarding the adoption/use of xR technology in flight training. Although there are noteworthy advantages (i.e., saving in time and cost, whilst also reducing risk), there are also significant drawbacks to the technology (i.e., BIP, hardware feedback, and familiarity with VR technology) that, moving forward, need to be addressed by hardware manufacturers and software developers. In general, however, the evidence is favourable to suggest that xR technology and VRFSs have the potential to benefit aviation and flight training. It could be concluded, then, that from the limited number data available to date, that evidence exists to suggest the use of xR flight training technology (i.e. VRFSs) at civil FTOs is an area worthy of further investigation and future research.

There is significant scope in this new area for civil FTOs and academia to partner and conduct research such as quasi-experimental studies involving student pilots, which could further support the use of advanced technologies in pilot training. From a practical perspective, there is little reason why FTOs with the right technical skills/experience can not begin to adopt VRFSs as part of their simulator solutions now, as there exists already data to suggest that this technology has the potential to benefit student pilots undergoing flight training today.

Virtual Reality is an emerging technology, although its use is becoming more widespread. Given the technological advancements and innovation being seen in this area, it is suggested that VRFSs could soon be a viable addition or adjunct to the methods presently being employed by FTOs, and potentially even come to replace them one day.

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Appendix A: MUHEC Application Approval

Date: 08 June 2021

Dear Glen Ross

Re: Ethics Notification - **4000024545 - Using focus groups to explore the uses of virtual reality technology in flight training.**

Thank you for your notification which you have assessed as Low Risk.

Your project has been recorded in our system which is reported in the Annual Report of the Massey University Human Ethics Committee.

The low risk notification for this project is valid for a maximum of three years.

If situations subsequently occur which cause you to reconsider your ethical analysis, please contact a Research Ethics Administrator.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:
"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director - Ethics, telephone 06 3569099 ext 85271, email humanethics@massey.ac.nz."

Please note, if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to complete the application form again, answering "yes" to the publication question to provide more information for one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand **T** 06 350 5573; 06 350 5575 **F** 06 355 7973
E humanethics@massey.ac.nz **W** http://humanethics.massey.ac.nz

Appendix B: Focus Group Guide

FG Outline Plan

Record: date, time, number of participants.

Greeting & introductions.

Purpose of the focus group

We are gathered here today to discuss your opinions on VR flight simulators and how they might be used in flight training.

Ground Rules

- Reminder of ethics approval given by the Ethics Committee and right to withdrawal at any stage.
- Confidentiality reminder (as per agreement).
- Role of Moderator: Observer only, will not be involved in the discussion—will interject only to keep the conversation on topic, or if the conversation *dries up*.
- Recording equipment—reminder that the FG is being recorded.
    - Please listen quietly and courteously to each other.
    - Please speak **one at a time** and as clearly as possible.
- Individual opinion or consensus (emphasise there are no right or wrong answers).
- Have all attendees turn off cell phones.

Icebreaker Exercise

Chronological history of VR hardware.

Introductions

When recording commences: State name & instructor category (first time of speaking only).

Focus group starter question:

It has been suggested that virtual reality technology could be used in flight training, and if implemented could potentially save time and money. As flight instructors, has anyone got any thoughts on this?

Conversation re-energisers (use if/when required)

- Where in the syllabus do you think they could be used (for what and how)?
- As flight instructors—tell me if there is anything you like about the technology.
    - Why?
- As flight instructors—tell me if there is anything you didn't like about the technology.
    - Why?
- Would *YOU* use them?
- What did you think about the virtual environment (VE)? Was it clear enough?
    - What was clear?
    - What wasn’t clear?
- Was the aircraft 'attitude' comparable to that of the real aircraft?
- What benefits (positive), if any, do you feel a VRFS could offer your students during flight training?
- What drawbacks (negative), if any, do you feel a VRFS could expose your students to during flight training?

Appendix C: Participate Information Pack

Virtual reality flight simulators: Focus group

INFORMATION SHEET

Project Description and Invitation

My name is Glen Ross. I am a flight instructor at the Massey University School of Aviation (SoA) and currently studying toward a Master of Aviation degree. As part of my degree, I am undertaking independent research into the potential application and uses of virtual reality (VR) flight simulators in flight training. I would like to invite you to partake in a focus group discussion aimed at finding out what current flight instructors think about this technology and its potential uses in a flight training context. It is my hope that this research will contribute to the body of existing knowledge on the methods employed by flight training organisations (FTOs) to train aviators in the future.

Background: Flight training, simulation and VR

Simulators have played an integral role in the training of aviators at all levels for over one hundred years. Since the 1920s, organisations responsible for flight training have used simulator technology to reduce costs, extend aircraft life, maintain flying proficiency, and provide more effective training.

As PCs have become more popular and powerful, flight simulation software like X Plane and Microsoft Flight Simulator has become more sophisticated. This has resulted in the complex world of flight simulation becoming less specialised and more generally available.

Virtual reality (VR) is a combination of wearable computer hardware and specialist software that delivers immersive, high-fidelity, three-dimensional content to the user via a head-mounted display (HMD) worn over the eyes. Coupled with sophisticated software, the HMD displays what is referred to as a virtual environment (VE), that the user may interact with and manipulate in real-time. Physical interaction with the VE can be achieved through a combination of specialist hardware (e.g., flight controls) and/or worn devices, called haptics, that provides sensation feedback.

Given the technological advancements in modern computing power, VR may now have to potential to offer a viable addition to the methods traditionally employed by FTOs by delivering high-value, realistic and cost-effective flight training.

Participant Identification and Recruitment

You were identified as a potential participant in this research because you are currently employed as a flight instructor at the SoA.

A total of ten flight instructors will participate in the focus group discussions, forming two groups of five participants. The composition of the focus groups will approximately match the ratio of A, B & C category instructors, as well as male and female staff, that currently exist at the SoA.

No financial compensation is available in return for participation, although coffee and biscuits will be made available as a token of my appreciation for giving up your time.

Project Procedures

At some point in the week prior to the focus group convening, I would like to invite you to have a go in the VR flight simulator currently situated at the SoA, so you have first-hand experience of the technology.

I will inform you of the exact date that the focus group will take place, this is dependent on instructor availability. The format of the focus group will be an informal conversation between you and four other SoA flight instructors and should take no more than an hour of your time.

My role as the moderator is to facilitate the conversation only and to keep it on topic, I will not be involved in the discussion.

The focus group conversation will be digitally recorded using an iPhone and iPad using dictation/transcription software. The conversation will later be transcribed for data analysis and used in the research.

Data Management

Anything you say will be treated in confidence by me, and I would ask that all participants please respect the privacy and confidentiality of others.

All collected data will be anonymised and no names will be used in the finished research.

The recording and transcription will be stored securely in an encrypted/password protected electronic folder on a Massey University PC.

Participant's Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded.

Project Contacts

Researcher: Glen Ross: xx xxx xxxx - xxxx.xxxx@massey.ac.nz
Supervisor: Dr. Andrew Gilbey: xx xxx xxxx - xxxx.xxxx@massey.ac.nz
You are invited to contact me or Dr. Gilbey at any time should you have any questions or concerns regarding the research or the conducting of the focus group.

Compulsory Statements

LOW-RISK NOTIFICATIONS

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director (Research Ethics), email: humanethics@massey.ac.nz

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Appendix D: Participant Consent Form

Virtual reality flight simulators: focus group

FOCUS GROUP PARTICIPANT CONSENT FORM

I have read, or have had read to me in my first language, and I understand the Information Sheet attached. I have had the details of the study explained to me, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I understand that I have an obligation to respect the privacy of the other members of the group by not disclosing any personal information that they share during our discussion.

2. I understand that all the information I provide will be kept confidential to the extent permitted by law, and the names of all people in the study will be kept confidential by the researcher.

Note: There are limits on confidentiality as there are no formal sanctions on other group participants from disclosing your involvement, identity or what you say to others in the focus group. There are risks in taking part in focus group research and taking part assumes that you are willing to assume those risks.

3. I agree to participate in the focus group under the conditions set out in the Information Sheet attached at Appendix 1.

Declaration by Participant:

I ____ hereby consent to take part in this study.
[print full name]

Signature: ________________________ **Date:** ________________

Appendix E: Biographical & Experience Questionnaire

Virtual Reality Flight Simulator Focus Group

Biographical & Experience Questionnaire

Initials:								
Age Range:	**Under 24**		**25–34**		**35–44**		**45–65**	
Highest Education Qualification:	**High School Certificate**		**Under-Grad Degree**		**Post-Grad Degree**		**Other (please specify)**	
Number of years flying:								
Total Hours:								
Instructor Rating:								
Number of years instructing:								
Total Instructing Hours:								