PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures;
Development, Validation and Effectiveness

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Abstract

Flying is a difficult and complex activity that requires a significant level of attention from the pilot as well as a lengthy training period to gain sufficient competency. For issues of both cost and safety, flight simulation has been an integral part of flight training from its earliest beginnings. There have been a number of technological developments and improvements in both the level of fidelity and the training effectiveness of flight simulators. As a result, flight simulators in use today are the result of this technological, psychological, and engineering evolution. Indeed, simulator cockpits can now accurately replicate all of the functions of flight controls and instrumentation found in real aircraft. Furthermore, the development of high-resolution display systems utilising computer-generated imagery (CGI), means that flight simulators can now display very realistic terrain and environmental effects.

The high cost of modern full motion flight simulators (FFSs) has meant that their use has generally been restricted to commercial airlines, military forces, and government agencies. More recently, rapid advances and decreasing costs in PC-based computer technology has enabled flight-training organisations to conduct more training with less expensive fixed-base flight training devices (FTDs). That said, the first study in this thesis indicated that in NZ, even the cost of certified FTDs is still beyond the reach of most flight training schools and their students.

The central tenet of this thesis is that a cost effective strategy for smaller flight training schools could be the utilisation of low-cost personal computer based aviation-training devices (PCATDs) for flight instruction and procedural training tasks. Although a number of studies have indicated that the fidelity of PCATDs may be quite low when compared to FTDs, especially in control loading and flight dynamics, there is some evidence of a positive transfer of training from the PCATD to the aircraft.

Significant research has been conducted on the effective use of PCATDs to reduce Instrument Flight Rules (IFR) training time in the aircraft. Conversely, few studies have examined the use of PCATDs for Visual Flight Rules (VFR) training. This lack of research is likely due to the limited fidelity of most PCATDs, especially in the critical area of visual displays. Customised PCATDs were developed to address these fidelity issues by utilising innovative and cost effective software and hardware technologies.

The aim of this study was to investigate potential training benefits and cost effectiveness of utilising low cost PCATDs, to improve pilot proficiency in performing VFR procedures. A quasi-transfer study was undertaken to ascertain whether a customised low cost PCATD was as effective as a Civil Aviation Authority certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation.

1. There was no evidence of a difference in VFR task performance between participants trained on the PCATD and the FTD when tested on the FTD. In addition, there were significant improvements in VFR task performance compared to a control group that received no simulator training.

2. A follow-up study compared VFR task performance of two groups with significantly different levels of aviation experience that were trained and tested on the PCATD. Again, there was no evidence of any significant differences in VFR performance between these two groups of pilot trainees and this demonstrated that the PCATD could impart equal training benefits to both experienced and ab-initio pilots.

The Civil Aviation Authority certification of two of the PCATDs developed in this study provided formal recognition of the training potential of these devices. In addition, the study has demonstrated that small to medium sized flight schools could enhance their training programmes significantly by deploying low cost PCATDs.

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Dedication

I would like to dedicate this thesis to my grandchildren

Taylor, Raiatea, Kauri, and Isaiah Reweti

who represent the future and all its possibilities

Table of Contents

List of Tables

List of Figures

List of Equations

Chapter 1. Introduction

1.1 Introduction

Personal computer based aviation training devices (PCATDs) are flight simulation devices that are based on desktop computer technology. They are characterised by their much lower cost than traditional flight training devices (FTDs), although cost is traded-off against some aspects of performance such as graphic realism and flight control fidelity. In addition, PCATDs do not require switches for functions such as fuel pumps, lights, magnetos, and starters, but must replicate basic operational functions such as landing gear, flaps, and avionics switches (Williams, 2006).

Twenty years ago, flight simulators were expensive, and designed in-house with custom components and proprietary software. Since then there has been a steady increase in the development of PCATDs using low cost commercial of the shelf (COTS) hardware and software (Mchale, 2009). PCATDs are comprised of three main components: PCATD software, flight controls and instrument display, and a personal computer (Elite, 2012b). The release of inexpensive but sophisticated software packages such as Microsoft Flight Simulator (MSFS) and X-Planes, combined with low cost PC-compatible technologies has accelerated the development of PCATDs. Despite initial scepticism from aviation authorities and flight training schools, PCATDs have become viable tools for presenting realistic, high-resolution, and full-size graphic displays of aircraft instruments (Elite, 2010; Taylor, Talleur, Rantanen, & Emanuel, 2004). These devices can also provide precise aerodynamic modelling, weather generation, and accurate depiction of high-resolution terrain. PCATD's can use a variety of low to medium fidelity input devices such as joysticks, throttles, generic knobs and switches, and realistic yoke/rudder pedal combinations (Williams, 2001a). However, PCATDs usually have low fidelity in the areas of cockpit layout, panels and switches, flight control loading, and flight dynamics (Noble, 2002). Despite these potential limitations, a number of studies have indicated that there is a positive transfer of learning when utilising PCATDs, and they do offer a low cost and effective alternative for aviation training, compared to more costly FTDs (Beckman, 1998; Koonce & Bramble, 1998; Taylor, et al., 2004).

The first PCATDs and FTDs that appeared as commercial products had low fidelity visual display systems so these devices were used almost exclusively for Instrument Flight Rules (IFR) training (Aerosoft, 2006; Frasca, 2006a; Stewart II, Barker, Weiler, Bonham, & Johnson, 2001). The reason for this was that instrument training is based on learning to fly without reference to out-of-cockpit visual cues. Technological advances in multiple-display technology, high-resolution terrain generation, and desktop PC processing speed have prompted more research into the effectiveness of PCATDs for Visual Flight Rules (VFR) procedural training (Roessingh, 2005). This could affect the way PCATDs are used as most general-aviation training activity is conducted under VFR criteria (CAANZ, 2011c). Nevertheless, only a very small percentage of simulator training hours are allocated to VFR task rehearsal. Most small to medium size flight-training organisations (FTOs) are well aware of the benefits of incorporating flight simulation into their ground-training programmes but for many the acquisition of a certified FTD is beyond their financial resources (Adams, 2008).

One possible solution to this problem is to acquire a low cost customised PCATD with sufficient fidelity to provide effective IFR/VFR flight training. There is now a range of commercially available devices with an array of technical capabilities (Elite, 2012d; Redbird, 2010). Nevertheless, they still have limitations in levels of fidelity and are only suitable for a narrow range of training tasks (Stewart II., Johnson, & Howse, 2008). In addition, there are still considerable doubts expressed by flight instructors about the training advantages of low cost PCATDs, and some have expressed concerns about negative transfer of training to the aircraft (Williams, 2006). One way of overcoming these concerns, as well as developing a versatile and effective PCATD for ground based flight training, would be to incorporate instructors and students feedback and evaluation within the overall design.

This study used a collaborative approach with instructional staff and students in several PCATD projects. Prototype devices were developed through a process of continuous incremental improvement. After several cycles of development and evaluation, the devices were then introduced into the training curriculum.

1.2 Statement of the Problem

Flying is a difficult and complex activity that requires significant attention from the pilot as well as a lengthy training period to gain sufficient competency to be authorised to fly (Wickens, 2004). It was apparent at an early stage in aviation that the utilisation of flight simulation devices could be a cost effective and safe method to assist with the task of teaching pilots to fly (Rolfe & Staples, 1989). The multitude of resources required to implement flight training impose a significant financial burden on many organisations that exist within the aviation training community. Therefore, aviation organisations have always sought more efficient and cost effective ways to simulate the processes of flight operation in a device other than the actual aircraft (McDermott, 2005a).

The most effective technique to decrease the costs of flight training is to incorporate a flight simulation device within the ground-training programme (Caro, 1988). Modern full-motion flight simulators designed for the commercial aviation industry are more economical than operating an aeroplane but normally cost as much or even more than the aircraft (Ortiz, 1994). Only civil aviation authorities can authorise the use of these full flight simulators (FFSs) which usually have six degrees of freedom (DOF) motion systems and high fidelity visual displays (CAANZ, 2006). Because of the high cost of procurement and maintenance of full motion simulators, FTOs have continued to investigate more cost effective ways of utilising flight simulation (Beckman, 1998; McDermott, 2005b). Rapid advances in computer technology have enabled flight simulator manufacturers to develop efficient and realistic fixed-base FTDs (Elite, 2012b). Several well established FTOs in NZ own and operate FTDs as an integral part of their flight training programmes (Massey News, 2007). Even though the cost of certified FTDs has fallen considerably in the last decade, they are still beyond the financial reach of most flight training schools in NZ (Frasca, 2007). NZ flight schools operate in a harsh economic environment with continued increases in the cost of aircraft maintenance, compliance costs, and aviation fuel. An alternative strategy is to use PCATDs for training, and the effective implementation of these devices could be critical to a flight school’s continued operation (Koonce & Bramble, 1998). PCATDs offer a low cost but effective alternative for flight instruction and procedural training tasks (Massey News, 2008).

Some PCATDs are small enough to fit on a large table, have similar flight controls and instrumentation as a real aircraft, and can emulate many of the features found in more sophisticated FTDs. The integration of these devices into a flight training school's syllabus can result in significant cost savings as some aircraft training and classroom instruction could be substituted with PCATD training. A number of studies have indicated that although the fidelity of PCATD's is quite low especially in flight control loading and flight dynamics, there is evidence of a positive transfer of training from PCATD to the aircraft (Koonce & Bramble, 1998; Taylor et al., 1999; Taylor et al., 2003). Other studies have indicated that the introduction of PCATDs into the training environment be treated with caution.

In some cases, PCATDs can offer a better learning environment than the aircraft but they do have limitations, and research suggests that they may be detrimental when used to teach psychomotor skills for basic flight manoeuvres (Dennis & Harris, 1998). If they have the potential to create poor flying techniques then for some students this may mean extensive retraining in the air. While they may be efficient and cost effective training tools for the rehearsal of procedures, their training effectiveness may decrease rapidly with overuse (Alessandro, 2008).Despite their limitations the use of PCATDs has grown steadily, and training sessions are now included in many pilot training programmes, especially for IFR skills training.

Although, the fidelity of PCATD software and hardware has improved significantly in recent years, little research has been undertaken to establish whether they are effective for VFR procedures training (Leland, Rogers, Boquet, & Glaser, 2009). Problems with limited field of view, lack of visual fidelity, and fixation on instrument displays by student trainees have caused flight instructors to question their effectiveness for VFR procedures training (Williams, 2006). The main goal of this research was to determine how PCATDs could be developed to be effective in IFR/VFR task skills training with a particular focus on VFR procedures and navigation. Flight instructors tend to be conservative and favour high fidelity FTDs as they mostly trained on these types of devices. They are, in most cases, reluctant to accept new technology such as PCATDs because they lack experience in using these devices and have limited knowledge of their training potential.

1.3 Purpose of the Study

The purpose of this research was to seek evidence of the benefits and cost effectiveness of using customised PCATDs to improve pilot proficiency in performing IFR/VFR procedures compared to a certified FTD. Five PCATDs were developed for use in pilot training programmes conducted by FTOs. These devices were developed as training aids to assist those organisations in improving the transfer of learning in flight training. This study focuses on the development of these PCATDs and in particular, a comparative study of the transfer of training effectiveness of a PCATD designed specifically for VFR procedures training and a certified FTD. The cost of this PCATD represented only a fraction of the financial investment required to purchase a commercially available Civil Aviation Authority of NZ (CAANZ) certified FTD. Evidence of the effectiveness of PCATDs for pilot training was based on the results of two comparative studies: A statistical analysis was used to determine whether a PCATD was as effective as a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation. Additional analysis compared the performance of a standard VFR traffic pattern operation on the same PCATD by two groups of pilot trainees who differed on experience and training organisation. The level of proficiency required for the correct execution of these VFR manoeuvres was based on the performance standards outlined in the syllabus of training of the CAA AC61-3 Private Pilot Licenses Advisory Circular (CAANZ, 2011e).

1.4 Research Objectives

The versatility of PCATDs has been proven in a number of studies but the historical focus has been on using these devices almost exclusively for IFR training. The primary objective of this research is to establish the effectiveness of low cost PCATDs for the training of ab-initio pilots in a broader range of flight training activities:

1. VFR flight training;
2. IFR flight training;
3. Aircraft emergencies training;
4. Remedial navigation.

An in-depth investigation spanning five projects was undertaken to determine the effectiveness of low cost, customised PCATDs compared to CAANZ certified FTDs in completing complex IFR/VFR flight-training tasks. In addition, what fidelity requirements were necessary to practice VFR task training effectively in the PCATD? A secondary aim was to provide further evidence that small to medium FTOs could benefit from:

1. Customised PCATDs designed specifically for their training requirements;
2. CAANZ certification of these devices (if required).

This study used a collaborative approach with flight instructors and students in several PCATD projects. Prototype devices were developed through a process of continuous incremental improvement. After several cycles of development and evaluation, the devices were introduced into the training curriculum. These PCATDs were designed to include four main components: basic flight controls, a digital instrument panel and visual display, customised flight model, and an accurate geographic terrain and airfield database. The acceptance and implementation of the customised PCATDs into the training curriculum involved a close collaboration between the PCATD developers and the instructional staff. The development of low cost customised PCATDs described in this thesis was characterised by five or six cycles: The adoption of these successive developmental cycles was influenced by several studies that investigated PCATD evaluation and development (CAANZ, 2011a; O'Brien, 2001; Smith & Caldwell, 2004; Stewart II, et al., 2001): The cycles were:

1. The adoption of an action research methodology;
2. Close collaboration with the sponsoring organisation;
3. Evaluation by qualified Subject Matter Experts (SMEs);
4. Empirical research into transfer of training effectiveness;
5. Implementation into the flight training curriculum;
6. NZ Civil Aviation Authority certification (if required).

At the commencement of this study, virtually all FTDs and PCATDs used by NZ flight training schools were developed by commercial companies based overseas (Elite, 2012d; Frasca, 2012b). Whereas local PCATD developers commonly used untested hardware technologies, combined with software and hardware interfaces that had to be developed in-house as there was no commercially available equivalents (Massey News, 2008). In addition, the production of training documentation for inclusion into the training curriculum can also be a challenging task for the PCATD developer (D. Walley, personal communication, 10 June 2008). Although the development of a customised PCATD is a difficult challenge, flight training can be significantly enhanced with the adoption of such cost effective technologies into the flight-training curriculum.

This thesis is comprised of five PCATD projects. Each project used an action research methodology which incorporated a process of continuous evaluation, feedback, and improvement. The projects included development and evaluation of:

1. A IFR/VFR PCATD for training ab initio military pilots;
2. A IFR/VFR PCATD for training helicopter rescue pilots and aircrew;
3. A VFR PCATD for navigation training and remedial VFR training;
4. A VFR PCATD for navigation and VFR training, and for use in a comparative empirical study;
5. An IFR/VFR PCATD for glass cockpit and scenario based flight training.

Two minor project extensions included:

1. A VFR PCATD for solo rehearsal Private Pilot Licence (PPL) training of military Unmanned Aerial Vehicle (UAV) operators;
2. A PCATD compatible VFR Search & Rescue Search Pattern Training Module.

Chapter 2. The Emergence of PCATDs

2.1 Introduction

The development of PCATDs has been characterised by the adoption and utilisation of relatively low cost technologies (Go Flight, 2010; Microsoft, 2010). This chapter examines the emergence and subsequent impact on flight training of the implementation of low cost PCATD technologies. In addition, it examines how these new technologies have reduced the construction time, acquisition costs, and maintenance costs of flight simulation devices.

Some of the earliest flight simulators were quite generic and used components with similar characteristics to those found in modern PCATDs. For example, low cost PCATDs have used components such as compressed-air shock absorbers, car seats, fabricated flight controls, and replica switches sourced from many non-aviation suppliers. The Link Trainer prototype was developed in 1929 from components acquired and adapted from sewing machines and other non-aviation related mechanical devices (ASME International, 2000). These simulators became famous during World War II, when they were used for pilot training by almost every nation. (Kesserwan, 1999). Despite their popularity, these simple but effective simulators were quickly surpassed as aircraft and flight simulator manufacturers began to increase the level of fidelity of new devices. The development of electronic and digital simulators accelerated the technological advances in fidelity levels but added further cost and complexity (Rolfe & Staples, 1989).

Simulator manufacturers invested large amounts of capital to research and develop these sophisticated flight-simulation devices. To protect their intellectual property they patented the devices and ensured that the software and hardware architecture was proprietary (Frasca, 2011a, 2011b). The recent advances in PC-based flight simulation have meant a much wider dissemination and access to flight training devices. The economics of flight simulation has fundamentally changed in that simulators can now be acquired with much lower levels of capital investment. The cost of simulation was in the past a prohibiting factor but now has become an economic advantage (Koonce & Bramble, 1998).

One critical area has been the development of accurate and versatile flight simulation software packages some of which cost less than an hour of flight instruction in an aircraft (Beringer, 1996). It could be argued that the production of hardware such as low cost flight controls, instrument panels, and visual displays has been as equally influential in the development of PCATDs (Koonce & Bramble, 1998). The emergence of the first desktop computer simulators did not occur until the early 1980s, when personal computers became readily available at a reasonable cost and inexpensive flight simulation software was developed. Computers such as the Apple II, TRS 80 Model 1, Atari ST, and IBM compatibles provided the first hardware platforms to run early flight simulation software such as subLOGIC Flight Simulator 1 and IFT-Pro 5.1 (Lamb, 2012). These basic software packages were surpassed by new and more versatile software, which was designed for the entertainment market. These included: Microsoft Flight Simulator, released in 1982 (Grupping, 2009), X-Planes, released in 1993 (Wardell, 2010), and Flight Unlimited, released in 1995 (McDonald, 1997). Soon after the release of these software packages, flight training schools, and aviation enthusiasts began to explore their potential for inclusion into low cost flight training devices (RNZAF, 2012).

In 1983, Frasca International began building dedicated, digital PC-based flight simulators. A year later the company developed flight control force feedback systems and the following year, its first visual system (Adams, 2008). In 1987, the Electronic IFT Training Environment (ELITE) company developed its first IFR training software package and after initial success moved quickly on to develop desktop trainers (Elite, 2012a). These companies continued to grow and dominate the development of proprietary FTDs and PCATDs for medium sized (50-100 students) flight training schools (Adams, 2008).In 1990, Precision Flight Controls (PFC) began to develop relatively high fidelity (COTS) flight controls systems, which could be incorporated into customised PCATDs built by researchers, and amateur flight simulation enthusiasts (PFC, 2000). These flight control systems were used in major studies commissioned by the FAA to establish certification requirements for PCATDs (Taylor et al., 1996).

By the late 90s, a number of small companies had formed to service the increased demand for relatively low cost desktop simulators, flight controls and avionics, and began to release a range of devices into the marketplace (Elite, 2012d; Go Flight, 2010; SimKits, 2010). In 2003, ELITE was the first company to gain FAA approval and additional flight training credit in the Advanced PCATD category, for its ELITE iGATE® Model G500 PCATD. The FAA would authorise it under Title 14 Code of Federal Regulations (14 CFR) Parts 61 and 141 (Elite Simulation Sytems, 2003). Flight training schools, pilot trainees, and system developers began to incorporate many of these COTS hardware and software components in prototype PCATDs (Massey News, 2008). The advantages of using these sub-systems were due to a number of factors:

1. Research and development had been already completed on these components;
2. They were relatively low cost;
3. Their adoption reduced the overall development time of a PCATD;
4. They had robust PC-based hardware and software compatibility;
5. Most components were also compatible with Microsoft Flight Simulator.

Many of these systems had already been used in PCATDs that had gained civil aviation authority certification and therefore had proven levels of fidelity, and conformity (Elite Simulation Sytems, 2003; Ruscool Electronics, 2011).

2.2 PCATD Software

Initially, aviation enthusiasts with home computers provided a ready market for flight simulator programs that could run on personal computers. The designers of these software packages had to choose between two distinct software architectures; the Newtonian system[1] (e.g., Microsoft Flight Simulator) or the Computational Fluid Dynamics CFD) model[2] (e.g., X-Planes). Each software package had its own advantages and disadvantages and a significant amount of time was taken by PCATD developers to evaluate the software.

[1] The Newtonian system uses non-dimensional aerodynamic coefficients. These coefficients are a linear-representation of an aircraft's aerodynamic forces and moments. When used with the aircraft geometry, mass and dynamic pressure, a calculation can be made for -all forces and moments on an aircraft (Zyskowski, 2010).

[2] CFD uses blade element theory. This process involved breaking the aircraft into small elements and then calculating the forces and moments on each of these small elements many times per second (Meyer, 2010).

Eventually these software packages running on increasingly powerful personal computers were exceeding the visual display capabilities and computing power of legacy full-flight simulators (Koonce & Bramble, 1998).

2.2.1 X-Planes

The software package, X-Planes Version 1.0, was released in 1993 by Laminar Research Ltd. and became a direct competitor of Microsoft Flight Simulator (Wardell, 2010). Most flight-simulator software packages use a Newtonian method for simulating the real world performance of an aircraft. MSFS defines the flight control characteristics of its aircraft flight models by using non-dimensional aerodynamic coefficients. In addition two-dimensional mathematical tables are also used to capture the non-linear behaviour of these aircraft models when subjected to extreme angles of attack or sideslip (Zyskowski, 2010). The X-planes creator argued that flight simulation programs like MSFS can accurately simulate aircraft with well-documented aeronautical performance. However, MSFS cannot accurately predict the performance of experimental aircraft where there is little performance data available (Wardell, 2010).

Therefore, Laminar Research decided to develop a flight simulator program using a (CFD) process to model the aircraft. This technique can result in the rendering of an accurate flight model representation of the real aircraft but requires substantial computer processing power to achieve. A distinct advantage is that the CFD blade theory[3] approach allows for a quick design and testing process for experimental aircraft prototypes. Laminar Research has subsequently released ten versions of the software (Meyer, 2010). The X-Planes scenery covers terrain from 74˚ north to 60˚ south latitude and over 33,000 airports have been modelled in the terrain. X-Planes software has a dynamic weather module with the functionality to allow users to download real weather from the internet.

[3] Blade-element theory is a technique of modelling the forces and moments on an aircraft by evaluating the parts that constitute it (Meyer, 2010).

The software also includes modules that enable the user to program individual systems to fail for training purposes. X-Planes software is popular with aircraft manufacturers and aviation training organisations for flight training and designing new aircraft concepts. For example, the Scaled Composites Company used X-Planes to simulate 'Space Ship One' flights in their pilot training simulator. Similar to Microsoft Flight Simulator, X-Planes has received limited FAA certification when combined with approved hardware so that pilot trainees can log simulator hours towards aviation licences and ratings (Wardell, 2010).

2.2.2 Microsoft Flight Simulator

In the 1980's, the first flight simulator programs began to emerge which could operate on a personal computer. A company called SubLOGIC that produced popular flight simulation software for a variety of computers including Tandy Radio Shack (TRS-80) and Apple II (Lamb, 2012). Two years later Microsoft licensed subLOGIC to produce a version for the IBM PC, which was designated as version 1.01 (Grupping, 2009). Microsoft released its inaugural flight simulation software package in 1982, and continued to support it with multiple upgrades until its last major release, Microsoft Flight Simulator X (FSX) in 2006. Improved versions were released in parallel with the development of improved PC hardware technology and increased consumer demand. A list of software versions and their date of release are outlined in Table 2-1.

Microsoft has always adopted an open software architecture policy when developing new versions in the MSFS franchise (see Appendix A1). The company also released Software Development Kits (SDK's) for most versions of MSFS so that third party software developers could easily modify the terrain, aircraft flight models, and aircraft panels (MSFS 2004 SDK, 2012). A significant extension of FSX was released in 2008 specifically designed for commercial aviation training and designated as Flight Simulator ESP (Microsoft ESP, 2007). MSFS is now one of the longest running and most successful game franchises in the world. By 1999, approximately twenty one million copies of MSFS had sold worldwide (Alessandro, 2008).

Table 2-1. MSFS Versions

Microsoft Flight Simulator Versions 1982-2012			
1982	Microsoft Flight Simulator 1.0	1984	Microsoft Flight Simulator 2.0
1988	Microsoft Flight Simulator 3.0	1989	Microsoft Flight Simulator 4.0
1993	Microsoft Flight Simulator 5.0	1994	Microsoft Flight Simulator 5.0a
1996	Microsoft Flight Simulator 5.1	1996	Microsoft Flight Simulator for Windows 95 v 6.0
1997	Microsoft Flight Simulator 98 v 6.1	1999	Microsoft Flight Simulator 2000 v 7.0
2001	Microsoft Flight Simulator 2002 v 8.0	2003	Microsoft Flight Simulator 2004 v 9.0
2004	Microsoft Flight Simulator 2004 v 9.1	2006	Microsoft Flight Simulator X v10.0
2007	Service Pack 1 for Flight Simulator X	2007	Microsoft Flight Simulator X Acceleration Pack
2007	Service Pack 2 for Flight Simulator X	2008	Microsoft Flight Sim X Deluxe
2009	Microsoft Flight Simulator ESP	2012	Microsoft Flight

Source: (Havlik, 2010). Czech Flight Simulator History Website -Timeline.
Retrieved from http://www.volny.cz/havlikjosef/timelineenglish.htm

In 2007 FSX was the ninth best-selling game in the United States with 280,000 units sold (QGN, 2007). By 2009, annual sales of FSX in the United States had increased to 1,000,000 units (Magrino, 2009). Microsoft has incorporated a continuous cycle of software improvements for MSFS over the last thirty years and this has meant that two of the latest versions FS2004, and FSX, have become immensely popular software packages (Alessandro, 2008). The popularity of the software design is also due to the detailed propulsion simulation techniques, ground reaction fidelity and advanced systems modeling that has been developed to produce many unique aircraft simulation features (Zyskowski, 2010). These simulation components are detailed in Appendix A2. The terrain displayed in MSFS encompasses the whole world, and includes over 24,000 airports with at least twenty to thirty highly detailed airports and cities. The latest versions incorporate sophisticated weather simulation, and a varied air traffic environment with interactive Air Traffic Control. There are also interactive lessons and comprehensive aircraft operational procedures checklists. (Baker, 2003; Lackey, 2006). A distinct advantage for PCATD development is the large number of third party companies producing a wide variety of compatible software (Flight 1 Aviation Technologies, 2011; RealityXP, 2007). A comparison between previous versions of MSFS demonstrates a significant improvement in the realism of the external display and the cockpit systems display. The screenshots in Appendix B1 clearly indicate the increased display resolution from early versions (MSFS 1 & 2) with 320 x 200 pixels to later versions (MSFS 10) with graphic arrays exceeding 1400 x 1050 pixels. Primarily designed for entertainment, the increased sophistication of the software and the growth in the computing power of personal computers has meant that MSFS was being used less as a game and more as an aid for basic flight training (Beckman, 2009).

Bechtold (2008) compared the flight dynamics of the two most popular PC-based flight simulation programs, X-Planes and MSFS (Alessandro, 2008). Bechtold investigated factors such as aileron response, rudder response, and the effects of throttle changes at different speeds. Real world pilots commented that when simulating normal VFR flying, both simulation software engines performed realistically. Problems occurred when the software tried to simulate extreme manoeuvres such as spins or high speed stalls. The study indicated that Microsoft Flight Simulator’s default flight-dynamics model did not perform quite as well as X-Planes when executing these extreme types of manoeuvres.

Nevertheless, FS2004 and FSX software has a number of advantages over competing software packages such as X-Planes. This is mainly due to the superior rendering of high-resolution graphics in the Microsoft software, and the availability of large online databases of freeware aircraft, panels, and scenery. For example, on the freeware Flightsim.com website, the file library contains 16,000 FSX files and 69,570 FS2004 files (N. Anderson, personal communication, February 17, 2011). Microsoft as part of its open architecture policy, released Software Development Kits (SDKs) for FS2004 and FSX so that third party software developers could easily customise the terrain, aircraft flight models, and aircraft panels (MSFS 2004 SDK, 2012). SDKs contain software tools that can be used to insert customised code into MSFS and have stimulated the development of compatible GPS emulators, weather generation, and mission building modules. These modules were also developed for use in MSFS because of its accuracy, flexibility, and low cost (McDermott, 2005a; Stewart II, et al., 2001).

2.2.3 Microsoft Flight Simulator Visual Display

When the first versions of MSFS were released in the 1980's they provided only rudimentary graphic capabilities (see Appendix B1). These included nine different view directions, and low-resolution cockpit and scenery displays. The initial graphic displays were either monochrome or limited to four colours. Over the next thirty years, improvements in MSFS software have mirrored the technological improvements in dedicated graphics processor displays, which are now capable of producing millions of colours.

Current versions of MSFS now display highly detailed scenery across the whole earth and simulate increasingly complex flight models (MSFS 2004 SDK, 2012). To achieve these tasks, requires a PC with powerful computing and graphics capabilities. The successful collaboration between Microsoft software developers and Intel engineers over the years has now resulted in some of the highest resolution graphics ever displayed on a PC-based flight simulator (Purcell, 2009).

2.2.4 Microsoft Flight Simulator Terrain Synthesis

A significant advantage of using MSFS for training is its excellent terrain synthesis. Its open architecture allows for the addition of customised high-resolution terrain to improve the default scenery (Szofran, 2006). The terrain or scenery has to be accurate and as realistic as possible to assist students with flight training procedures such as navigation. The definition of the geographical features displayed in FS2004 and FSX had to be detailed enough to enable student pilots to navigate and recognise reference points depicted in the scenery database rather than by reference to instruments. FS2004 software utilises a layering system to render the default terrain and the scenery is classified into five categories (Harvey, 2004):

1. Landclass – the first layer is the surface of the earth split into a grid pattern and each cell is defined with a particular landclass (e.g., forest, water, and desert).
2. Elevation Mesh – this layer defines the elevation of each point on the grid that is used to determine the shape of the terrain. Topographical data extracted from the STRM satellite imagery database is then placed on top of this mesh.
3. Vector Scenery – this layer defines all the coastlines, lakes, rivers and roads. This level can also include default airports, buildings and autogen (e.g. auto-generated objects like trees, houses, bushes, and power lines).
4. Aviation Related Objects – this layer defines major airports, runways, windsocks, and navigation beacons. To ensure accuracy, placement data is extracted from aeronautical publications.
5. Dynamic scenery–this scenery layer includes moving objects such as Artificially Intelligent Aircraft, and vehicles, and other animated objects (e.g. turbines).

Microsoft used aerial photographs for its scenery but inconsistencies in colour and contrast reduced the quality of the aerial images. At the time, Microsoft did not wish to dedicate the significant resources required to correct all of these problems and produce a consistent worldwide database of imagery, so compromises were made in scenery resolution. When FS2004 was released, the default scenery was set to a resolution of 1200 metres between elevation points but New Zealand has a wide variety of geographic landscapes that change rapidly over short distances. Because the resolution was only 1200 metres, very small townships simply disappeared in the default scenery visual display.

Further improvements to the default scenery were made with the release of FSX, which used NASA Shuttle Radar Topography Mission (STRM) geographic data to render NZ scenery at twice the resolution (600m) of FS2004 (Szofran, 2006). Despite the improvements in the accuracy of the default terrain in successive versions of Microsoft Flight Simulator, visual database errors meant it was still not quite accurate enough to be used for VFR flight visual training.

2.2.5 New Zealand Terrain Mesh

Terrain mesh is generated by a computer software algorithm, which simulates real world geography (see Fig 2-1). It uses real world geographic elevation data combined with complex calculations (such as the curvature of the earth) to render computer generated 3D landscapes of real world terrain (Szofran, 2006). GeographX (A NZ mapping company) completely rebuilt the MSFS NZ mesh by using vector elevation data from a NZ topographical database. Geographx offered four different resolutions (150m, 75m, 40m, & 20m) of mesh scenery of NZ to cater for a range of PC processing capabilities (Stock, 2005).

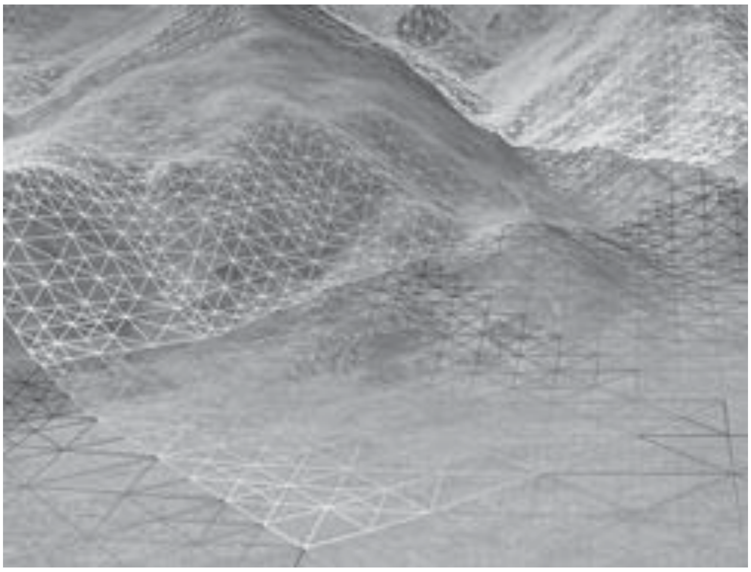

Figure 2-1. Terrain Mesh Simulation (Facsimile)

Source: (Szofran, 2006)- Global Terrain for Flight Simulation Fig.5.

The accuracy of the highest resolution 20m digital elevation model (DEM) was given as 10m and the horizontal accuracy as 20m, which was sixty times more accurate than the FS2004 default scenery. This high quality mesh scenery coupled with updated geographical vector[4] data provided an excellent platform to assist ab-initio pilots in

[4] Geographical vector data model represents geography as collections of points, lines, and polygons (Barnes, 2010)

identifying local geography (Stock, 2006). It was also superior to a 2D map in that it enabled trainee pilots’ to rehearse procedures in real time and develop the terrain and spatial; awareness necessary for successful cross-country VFR navigation (Williams, Hucthinson, & Wickens, 1996). A common way of measuring the accuracy of elevation data rendered in synthetic terrain is by the level of detail (LOD) that is displayed (see Table 2-2). The higher the LOD value, then the higher the resolution of the data (Martin, 2010). For example, LOD 12 has one elevation data point every 10m so scenery rendered at LOD 12 will have fifteen times the level of detail of LOD 8. LOD values are often used to catalogue the resolution of third party scenery developed for MSFS (Stock, 2006).

Table 2-2. Level of Detail vs. Resolution

Level of Detail (LOD)	Approximate Resolution (metres)
LOD 5	1200
LOD 6	600
LOD 7	300
LOD 8	150
LOD 9	76
LOD 10	38
LOD 11	19
LOD 12	10

Source: (Martin, 2010)- FSGlobal FSX. Retrieved from http://www.avsim.com/pages/0210/Pilots/FSGlobal.htm

2.2.6 Land Class

The Microsoft Flight Simulator landclass is raster-based, which means it is displayed on a rectangular grid of pixels. Raster graphics are resolution dependent and the scale cannot be increased without some loss of quality. The elevation mesh is also a grid of different elevation points spaced at 76 metres or 33 metres or whatever resolution that has been defined (Barnes, 2010). One has to imagine a blank virtual canvas, which is draped over this grid of elevation points. Microsoft Flight Simulator then places textures such as urban or rural textures on this virtual canvas and as you fly over the simulated terrain these texture files are repeated or changed accordingly (VectorLandClass, 2011).

2.2.7 Photo-Realistic Scenery

Microsoft decided to synthesise satellite imagery when producing Microsoft Flight Simulator default scenery mainly because of limitations in satellite imagery and aerial photographs available at the time (Szofran, 2006). Since then more high-quality satellite imagery and photographic resources have become commercially available. NZ freeware scenery designers have taken the opportunity to utilise these new resources and publish high-resolution regional upgrades to the Microsoft Flight Simulator scenery database (Warren, 2006).

The technique they used was to slice up the satellite image into tiles, which are then overlaid onto Microsoft Flight Simulator elevation mesh (Corn, 2009). Unlike repeating textures found in the default scenery, these tiled images are a depiction of real scenery. Because high-resolution satellite imagery is now being used, individual trees and rooftops can be identified (Aerosoft AustraIia, 2010). Nevertheless, displaying photorealistic scenery in real time requires the allocation of a high level of graphic processing resources and this can severely affect the overall processing speed of PC-based simulation systems. To maintain processing speed most scenery designers use a mix of photo realistic tiles with high resolution elevation mesh and high resolution landclass (VectorLandClass, 2011). A commercial NZ company, Godzone Virtual Flight (GVF) has utilised a combination of satellite data, proprietary datasets, and aerial photography to create highly detailed and localised photo realistic scenery modules (see Appendix P1). In many cases, these modules have been augmented with auto-generated scenery such as trees and combined with photo real modelled buildings (Corn, 2009).

2.2.8 Development of Local Airport Scenery

The development of high-resolution NZ scenery has been a crucial component of PCATD development in NZ (Stock, 2006). The utilisation of a PCATD for improving general aviation VFR skills requires the addition of accurate local airport models (most of which are not commercially available) and local VFR reporting points to the scenery database. Therefore, for general aviation training using PCATDs, many small airfields in the local region (see Appendix P2) have to be developed and customised to a high level of detail (Botica, 2012). Collaboration amongst NZ based scenery designers has led to the compilation and development of a significant number of localised scenery objects such as local airports, runways, and navigation beacons (Corn, 2009; Reweti, Baunton, & Butler, 2005). It is critical that trainee pilots can recognise large geographical features within the PCATD visual scenery as well as demonstrating correct aircraft orientation in relation to those features. Also, pilot trainees completing navigation training exercises in the PCATD require realistic depictions of waypoints and smaller geographical features so that they can accurately identify them in the real world (Bone & Lintern, 1999). Often student pilots fly in unfamiliar terrain while completing cross country navigation exercises (Williams, et al., 1996).

2.3 PCATD Hardware

Computers have gained CPU processing power, and the fidelity of high-resolution graphics Graphic Processing Units (GPU) has increased rapidly. This has resulted in an exponential improvement in flight simulator performance and levels of realism (Elite, 2012d). High performance computers also require the addition of flight controls with a reasonable level of fidelity to be effective for use in aviation flight training. To qualify as a PCATD, a PC-based computer system must have physical controls attached, and manufacturers are required to gain approval for each model (FAA, 1997). Regulatory authorities such as the FAA, and CAA, have a mandatory requirement that PCATD flight controls have a similar response time and a similar effect as controls in an actual aircraft.

All PCATDs must have a self-centering control stick or yoke, rudder pedals, and physical controls (not a computer mouse) for moving flaps, throttle, propeller RPM, mixture, pitch trim, communications and navigation radios, timers, landing gear levers, and other cockpit controls and instrumentation (FAA, 2008). The software and hardware components must be compatible because the hardware sends variables from sensors to the software by means of voltage and digital inputs (e.g., avionics frequencies, switches, and buttons). One technical requirement that the manufacturer must achieve is a communications and transport data latency not greater than 300 milliseconds for all analog and digital input signals (FAA, 2008). When the hardware manufacturer and the software developer cooperate to develop full compatibility between hardware and software modules this results in an integrated and flexible PCATD. In some situations, the hardware manufacturer and the software developer do not fully cooperate in developing the PCATD (RC Simulations, 2005). Therefore, the software is licensed for use to the PCATD manufacturer and incorporated into the device. If the software is licensed, the manufacturer must testify that all hardware technical requirements (analog and digital input values) are compatible with the software used in the PCATD. In addition, the manufacturer must also obtain a compatibility statement from the software developer (RealityXP, 2007). Because of this close cooperation a number of COTS hardware devices, which fulfilled the FAA technical criteria, have been developed by U.S. companies. The most popular devices have been manufactured by Precision Flight Instruments Inc. (PFC, 2012), GO Flight Avionics (Go Flight, 2010), and Simkits Avionics (SimKits, 2010).

2.3.1 Precision Flight Controls Inc.

Established in 1990, Precision Flight Controls, Inc. was quickly recognised by the aviation industry as a leading manufacturer of FTD and PCATD components (PFC, 2000). The company produces basic and advanced aviation training devices (BATD/AATD) that are both FAA and Transport Canada approved. Many of its control systems are approved by regulatory agencies such as CASA, ICAO, and the JAA. Precision Flight Controls flight training devices have been utilised in studies conducted by the FAA Human Factors Laboratory in Oklahoma City and NASA's Advanced General Aviation Transport Experiment (AGATE) (PFC, 2004). These flight control devices have sufficient fidelity and response time to be used in FAA certified PCATD’s (PFC, 2012). They were also less expensive (approximately $NZ1000 per unit) than legacy FTD flight control components and could easily be adapted to PCATD design. One major limitation of these controls was their lack of control loading or force feedback mechanisms (Frasca Technology, 2011).

2.3.2 Go Flight Avionics

In early 2000, Go Flight Inc. began designing and selling an array of simulated modules including a COMMS radio, NAV radio, ADF, and transponder. (Go Flight, 2010). The USB capabilities of these devices and their relatively low cost of approximately $US100 per unit have made them a popular choice amongst flight simulation enthusiasts in NZ. Because of the digital displays and reliability of these modules, they became an integral part of the Stage 1-4 projects. Currently GoFlight has seventeen different PC-based flight simulation modules. GoFlight has also achieved FAA certification for its ATD product line including its avionics components which was a significant criteria for their use in PCATD projects that require certification (Go Flight, 2010).

2.3.3 SimKits

SimKits is a department of TRC Simulators who also produce The Real Cockpit complete flight simulators. The TRC Development Company was established in 1999, and manufactures flight instruments, and avionics for the flight simulator industry. The TRC 1000 Garmin Replica Primary Function Display (PFD), and Multi-Function Display (MFD), as well as the Simkits Standby Gauges are components commonly used in glass cockpit PCATDs. All components are manufactured to FAA/Canadian Transport/JAA specifications (Simkits, 2011).

2.4 Flight Simulator Standards and Regulatory Approval

2.4.1 Introduction

The standard of flight simulators used for aviation training is subject to close regulatory control by a country’s aviation authority. In the USA, this is the Federal Aviation Administration **(**FAA**),** in Australia, the Civil Aviation Safety Authority (CASA), and in New Zealand, the Civil Aviation Authority (CAANZ). Only these agencies can approve training exercises and flight tests on approved simulators instead of in the aircraft itself.(CAANZ, 2006; CASA, 2002; FAA, 2008). The nature of these flight checks or tests depends on the experience of the pilot, and the type of simulator or trainer used. Simulator training exercises are conducted under strictly controlled conditions and provide the pilot with the opportunity to gain "credits" towards an appropriate flight crew qualification, instead of having to utilise aircraft flight time (Kesserwan, 1999).

2.4.2 The International Regulatory Situation

With emerging flight simulator technologies (e.g., PCATDs) and new pilot training methodologies (e.g., Scenario Based Training), current regulations on flight simulation were quickly becoming outdated. Most National Aviation Authorities (NAAs) had implemented some regulatory changes (CASA, 2002; FAA, 2006). The European

Aviation Safety Agency (EASA) adopted the former European Joint Aviation Authorities (JAA) rules, and the United States' Federal Aviation Administration (FAA) implemented its Part 60 regulation. Nonetheless, there was very little harmonisation between the various NAA's in relation to flight simulator approvals (ICFQ, 2009). The development of the Multi-crew Pilot Licence (MPL) by the International Civil Aviation Organisation (ICAO) was designed to allow much greater use of flight simulation, but only highlighted the inconsistencies in the definition of simulator device levels between different NAAs (CASA, 2012).

During 2001, a group working under the joint authority of the FAA and the JAA held meetings to review the standards contained in ICAO 9625 Edition 1. The updating of the minimum standards for flight simulator qualification culminated in the release of ICAO 9625 Edition 2 in 2003 (ICAO, 2003). This second edition had one major limitation in that it did not address the standards required for the complete range of Flight Simulation Training Devices (FSTD's). Therefore, other NAAs decided at the time to develop their own standards for the lower level FSTD's (Cook, 2006). In 2006, Cook of the Federal Aviation Administration (FAA) promoted the formation of an International Working Group (IWG) during a symposium at the Royal Aeronautical Society (RAeS) in London. In his presentation, he argued that although new qualification requirements for the highest level of full flight simulators (ICAO 9625 Edition 2) had been completed, internationally accepted criteria for the classification of lower level FTDs had not been addressed (Cook, 2006). In the past the technical capabilities of the flight simulator determined how the devices were used in training.

The task of the working group was to develop a new system of classification to include all devices from desktop trainers to full-flight simulators for both fixed-wing aircraft and helicopters, based on the performance of specific pilot training tasks (Cook, 2006). The IWG undertook an in-depth review of the simulation fidelity levels necessary to support the required training tasks for each type of license, from private pilot (PPL) to air transport pilot (ATPL). The working group formed into two subgroups, training, and technical. For each task on the list, the training subgroup decided the level of fidelity generic, representative or specific to the aircraft, required for each of 12 features of the simulator, including cockpit, flight model, systems, engines, flight controls, visual, motion and environment, such as airport and terrain, air traffic control, and weather (Strachan, 2008).

The result of the IWG's review was the development of a comprehensive matrix that matched 150 training tasks with each of the 12 license and rating types, and assigned fidelity levels to each of 12 simulator features. The technical subgroup then examined the results of this training analysis and looked for logical groupings of fidelity levels. This led to a new classification of seven new device types - Levels 1 to VII - spanning the complete range of training device from desktop trainer to full-flight simulator (see Fig. 2-2). The IWG achieved a major milestone when the ICAO 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices Edition 3 Vol.1 - Aeroplanes was completed and subsequently promulgated by ICAO in 2009 (ICAO, 2009).

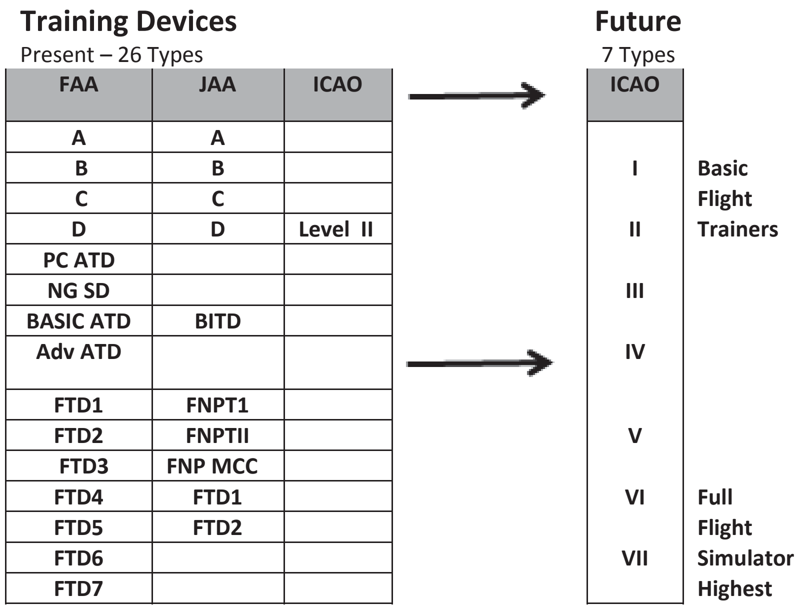

Figure 2-2. New ICAO FSTD Standards (Facsimile)

Source: (Strachan, 2008, p.1).
http://www.raes-fsg.org.uk/uploads/081216123730_200810_RAeS_Flight_Simulation_Initiative.pdf

The new ICAO FSTD standards have streamlined the complex and bewildering array of twenty-six different category types promulgated by FAA, JAA, and ICAO down to seven well-defined categories. The highest category is Level 7 (VII), which is similar to the current Level D flight simulator classification but does include additional enhancements in visual fidelity, and Air Traffic Control communications simulation (Strachan, 2008).

To date, only two NAA's, Singapore and Russia have fully adopted ICA0 9625 Edition 3. There is support from EASA who have advised ICAO that its adoption of ICAO Doc 9625 is scheduled for 2014. The FAA advised that it was likely that two out of seven ICAO FSTD classifications would also be adopted (ICFQ, 2009). CASA has implemented a project towards achieving full compliance and is currently reviewing its CASR Part 60 Rule (CASA, 2010).It is also amending its Operational Standards and Requirements– Approved Synthetic Trainers (FSD-2) Manual. The New Zealand Civil Aviation Organisation (CAANZ) has adopted ICAO 9625 Edition 3 in principle, and is working towards implementation.

The commercial flight simulation market continues to be influenced by the tension generated between rapid advances in technology and the demand for new certification and regulation (Strachan, 2008). Traditional qualification standards for flight simulators developed by NAAs have failed to keep pace with the rapid advances in synthetic training and new training methodologies. The development of ICAO 9625 has provided a pathway for change (Cook, 2006). In recent years, collaboration with the aviation industry has accelerated the process to simplify and harmonise flight-simulator qualification standards and therefore make training safer and more efficient (ICAO, 2003, 2009). Aviation training is a global industry and the emphasis is now towards continually improving international standardisation. The delay in adoption of ICAO 9625 by EASA and FAA demonstrates that the adoption of a new standard can be a lengthy and complex process (ICFQ, 2009). Despite the difficulties, increased standardisation will greatly assist commercial operators in securing annual approvals from the many regulatory authorities that qualify simulators for training so that they may continue to utilise these devices for flight training (Strachan, 2008).

2.4.3 Regulatory Approval of PCATDs in the USA

Studies conducted in the 1990's indicated that procedural understanding of instrument flight tasks could be taught during ground training using PCATDs. For example, the Aircraft Owners and Pilots Association (AOPA) and the Air Safety Foundation (ASF) had been studying PCATD's for several years and in 1994 reported that they were suitable for aviation training (Landsberg, 1997). In 1995, the ASF petitioned the FAA for an exemption to the instrument rating regulations to allow a credit of 14.5 hours of PCATD training time toward the 40-hour instrument rating. ASF also requested that they be allowed to conduct more formal tests in a controlled environment (Landsberg, 1997). Conversely, the aviation training industry still regarded PCATDs as being of questionable value when used to train pilots in basic instrument, and visual flight rules (McDermott, 2005b). Although previous studies had indicated positive transfer (Hampton, Moroney, Kirton, & Biers, 1994; Phillips, Hulin, & Lamermayer, 1993). The FAA considered the lack of control groups, variable manipulation, and task limitations as significant obstacles to allowing more PCATD activity in FAA approved aviation training schools. Nevertheless, during this intense period of PCATD development, manufacturers and potential users pressured the FAA to reconsider their opposition to certifying PCATDs. Eventually the FAA reversed its decision and began to evaluate several PCATD hardware and software applications (McDermott, 2005a).

One of the FAA's primary objectives was to determine whether relatively low cost aviation training devices had any potential for use in general aviation and instrument flight training (FAA, 1997). These evaluations were conducted to investigate whether certification or aviator recency of experience requirements could be met using such devices (FAA, 1999). The FAA's investigation and final decision to allow the use of PCATD's for instrument flight training took over six years to complete and was based on the results obtained in two major studies (FAA, 2008).

The first of these studies by Hampton, Moroney, Kirton, & Biers (1994) focused on measuring the flight performance of students trained using PCATDs compared with the performance of students trained using a certified FTD. The in-flight performance of aviation students trained on PCATDs, was compared to the in-flight performance of students trained in an FAA approved Frasca 141. Seventy-nine students enrolled in an IFR course were trained on one of three training devices and were then tested in a Mooney 20J aircraft. Student performance was evaluated by course instructors on six manoeuvres and two categories of general flight skills. Compared to students who trained on the Frasca, students trained on the PCATD required significantly fewer hours and trials per task, to reach the overall test standard required. There was no control group in this study so it was not possible to establish the transfer effectiveness of the PCATDs, or the Frasca 141 FTD.

In the second study, Taylor, Lintern, Hulin, Talleur, Emanuel, & Phillips (1996) compared the performance of university students who received some pre-training on a PCATD before commencing their training in an aircraft with the performance of students trained only in an aircraft. One hundred and seven students participated in this study and they were randomly assigned to a PCATD group, or an aircraft control group. Flight instructors rated student performances on instrument tasks in both the PCATD and the aircraft for the PCATD group. For the aircraft-control group, instructors rated student performances only in the aircraft. Rater inter-reliability between the twenty instructors was estimated to be as high as 0.80. Comparisons of trials to criterion in the aircraft, times to complete each flight lesson in the aircraft, and course completion times were used to calculate the training effectiveness of the PCATD. There were positive transfer effectiveness ratings when new tasks were introduced but reduced effectiveness ratings when reviewing previous lessons. A comparison of course completion times showed savings of 3.9 hours in the aircraft for the PCATD group compared to the aircraft-control group.

Because of the positive outcomes of these two studies, the FAA determined that there was sufficient justification to allow the use of PCATDs for training purposes (FAA, 1999). New PCATDs had to meet acceptable standards for meeting some of the training requirements for an instrument rating under the applicable provisions of Part 61 or Part 141 (FAA, 1997). It was determined that FAA certified PCATDs may be beneficial when used under the guidance of an authorised instructor to achieve learning in certain procedural tasks such as area departures and arrivals, navigational aid tracking, holding pattern entries, instrument approaches, and missed approach procedures (FAA, 2012b). Nevertheless, the FAA formulated a stringent policy at the time. For any flight simulator training used to log time toward meeting any requirement of the regulations, an authorised instructor must have presented the instruction. In addition, the FAA made it quite clear that it did not authorise the use of PCATDs for conducting practical tests nor for accomplishing recency of experience requirements (FAA, 1997). To maintain the required instrument currency experience, a pilot has to complete the following instrument flight procedures within the preceding six months (FAA, 2009) :

1. Six instrument approaches;
2. Holding procedures;
3. Intercepting and tracking of navigation signals

In 2009, the FAA formally published revisions to the 14 CFR Part 61 rules that authorised the certification of pilots and flight instructors. These amendments outlined changes to existing regulations governing the use of a Flight Simulator (FS), Flight Training Device (FTD), and Aviation Training Device (ATD) for training and in particular instrument proficiency. The new rules provided for greater flexibility in the use of these devices, in training for certificates, ratings, and to maintain instrument currency (FAA, 2009). A mandatory requirement is that the simulation devices must be representative of the category of aircraft that the pilot is training on for instrument rating certification or for maintaining instrument currency. The following FAA rules now apply to instrument currency training (FAA, 2009):

1. A pilot may complete the required recent instrument flight experience on a FS or FTD *within six months* before the month of the flight.
2. A pilot may complete the required recent instrument flight experience on an ATD but *within two months* before the month of the flight.
3. A pilot may combine the use of the aircraft and FS, FTD, and ATD by completing one hour of instrument flight time in the aircraft and three hours in the FS, FTD, or ATD *within six months* before the month of the flight.
4. A pilot may combine the use of an FS or FTD, and an ATD by completing one hour in a FS or FTD, and three hours in an ATD *within six months* before the month of the flight.

The rationale for the promulgation of these new regulations was to recognise that the utilisation of ATDs (commonly called PCATDs) could provide equivalent benefits in instrument training to that of flight simulators and flight training devices.

Nevertheless, some restrictions in time were made in terms of currency between ATDs (2 months) and FTDs (6 months). This difference in time was an acknowledgement that FTDs usually have higher levels of fidelity and are more representative of the training aircraft than an ATD. Another clarification was that the FAA did not specifically approve flight simulator software such as Microsoft Flight Simulator or X-Planes. The FAA may approve FTDs and ATDs that include this type of software plus displays, controls, and other features (FAA, 2008).

2.4.4 Regulatory Approval of PCATDs in Australia and New Zealand

In 2001, because ICAO 9625 Edition 2 did not provide specific approval levels for lower level FSTDs, CASA, like other regulatory bodies, began to formulate its own policy for the approval of these devices. In their proposal for regulatory change, CASA outlined various options for reclassifying simulator types to better align them with training needs in Australia, with the proviso that further alignment with FAA and JAA standards was the preferred option (CASA, 2002). CASA implemented several key changes for reclassifying simulator types including the adoption of three new categories. Synthetic Trainer (ST), Flight Training Device (FTD), and Flight Simulator (FS). PCATDs were placed into the Synthetic Trainer category. This culminated in the release of the CASA publication "Operational Standards and Requirements–Approved Synthetic Trainers (FSD-2)" in 2002 (CASA, 2002). In the FSD-2, emphasis was placed on the development of a comprehensive Synthetic Trainer Operations Manual (STOM) that must be provided with the training device. A STOM had to include:

1. A copy of the Synthetic Trainer Certificate (STC) approval;
2. A list of approved flight instructors;
3. An equipment list;
4. Maintenance schedule;
5. Calibration record;
6. Operating procedures for Pilots;
7. Operating procedures for Flight Instructors;
8. Log Book (CAANZ, 2007a).

In 2006, the CAANZ promulgated a Notice of Proposed Rule Making (NPRM) "Standards for use of Simulators" but a formal rule has yet to be released. CASA had already developed the FSD-2 manual, and as both countries had similar aviation training programmes, the CAANZ adopted the publication as the primary source for its FSTD approvals (J. Parker, personal communication, May 17, 2011). In accordance with the guidelines outlined in FSD-2 the CAANZ produced an additional manual "Guidance for the production of a Synthetic Flight Trainer Manual (SFTM)" (CAANZ, 2007a). This manual has similar criteria outlined in the FSD-2 STOM but expanded on the requirements to include:

1. The training required by the Synthetic Flight Trainer (SFT) instructor to gain authorisation to operate the simulator for training purposes.
2. A training syllabus appropriate for simulated instrument flight training on the SFTD.

In 2011, CAANZ promulgated a new simulator accreditation application. The new form's title was "Application for Accreditation of a New or Modified Aeroplane Flight Simulator for Approved Uses" (CAANZ, 2011a). The application defines three types of Synthetic Training Device, which was similar to the categorisation described in FSD-2:

1. Flight Simulator – Realistic simulation of full flight deck;
2. Procedure Trainer - Representation of flight deck and aircraft type;
3. Basic Instrument Trainer –Simulation of flight deck for IFR training.

The application criteria also focused on the relevant CAANZ rule in relation to pilot training and proficiency requirements. The training requirements included experience, recent flight experience, training programme, and type endorsement. The proficiency requirements included flight instructor and flight crew competency checks, instrument rating recency, and type endorsement (CAANZ, 2011a). These regulatory criteria have been in force in the Australian and NZ aviation training community since 2003, and PCATDs developed in NZ are assessed and certified under the criteria of FSD-2 and the CAANZ STFM guidelines. PCATDs are designated by CAANZ as Synthetic Flight

Trainers (SFTs) and can be approved for the purpose of accumulating aeronautical experience under provisions contained in AC 61-17 Pilot Licences & Ratings-Instrument Ratings (CAANZ, 2011d). They are classified as flight procedure trainers and may be approved for the purposes of:

1. Accumulating instrument ground time;
2. Maintaining instrument rating currency;
3. Maintaining instrument approach currency;
4. Completion of an instrument rating annual competency demonstration;
5. Completion of the demonstration required for an additional make and model of a Global Navigation Satellite System (GNSS) navigation aid.

The authorisations that may be issued to a Synthetic Flight Trainer in NZ are outlined in Appendix G2 and H2 (CAANZ, 2007a). Unfortunately, the regulatory standards for Synthetic Trainers, defined in FSD-2 are now out of date and are not internationally recognised. CASA's intention is to update its Civil Aviation Safety Regulation CASR Part 60–Synthetic Training Devices to be more consistent with the new ICAO 9625 Edition 3 requirements and replace obsolete standards (CASA, 2010).

2.5 The Effect of Fidelity on Flight Simulation

2.5.1 Introduction

In the past, a regulatory body's simulator approval was determined largely by the level of fidelity of the flight-training device (AGARD, 1980) This is in accordance with Osgood's (1949) transfer surface concept. The closer the correspondence is between the features of the simulator and the simulated equipment, the higher the level of positive training transfer. High-fidelity simulation has several distinct characteristics. Two of these are a high level of scene detail, and simulation of motion. Scene detail contributes to the realism of the out-of-cockpit view seen by the pilot trainee (Goss, 1991).

It is a common belief that high scene detail is more realistic and enhances pilot training, and experiencing motion cues similar to the real aircraft assists in a positive transfer of training (Lintern, Koonce, Kaiser, Morrison, & Taylor, 1997; Vaden & Hall, 2005).

The assumption is that the more realistic a simulation is perceived by the pilots, the more their behaviour in the flight simulator mimics that exhibited in the operational environment. Dion, Smith, & Dismukes (1996) characterised the aviation industry's position on high-fidelity simulation, by arguing that the closer the similarity between the simulator and the aircraft, then the more effective the instruction. Despite Dion et al’s findings, a number of researchers have questioned the validity of this approach (Dahlstrom, Dekker, van Winsen, & Nyce, 2009; Roscoe, 1991; Salas, Bowers, & Rhodenizer, 1998). The link between maximum fidelity and maximum training transfer is taken on faith, and the assumption is that if it looks real it will provide good training (Stewart II., et al., 2008).

2.5.2 Physical and Functional Fidelity

The term fidelity is commonly used to describe the degree of similarity between the simulated and operational environments (Alessi, 1988). The categorisation of flight simulators into two classes depends on the nature of the cues they provide:

1. Physical fidelity - Equipment cues provide a duplication of the look and feel of the aircraft. The static and internal dynamic characteristics such as the size, shape, location, type of controls and displays, including flight control feedback and displacement characteristics.

2. Functional fidelity - Environment cues provide a duplication of the environment and motion through the environment (Alexander, Brunye, Sidman, & Weil, 2005).

Physical fidelity encompasses a number of different dimensions. These include visual, auditory, vestibular, olfactory, proprioceptic, and other senses that are directly affected by equipment cues in a training simulator. While expensive full flight simulators can recreate high fidelity visual cues and exact instrument operation (i.e., physical fidelity), low cost PCATDs are ideal for recreating interactivity (i.e., functional fidelity) across a range of users in a variety of settings and locations (Lewis & Jacobson, 2002). Flight simulator systems can vary in their degree of physical and functional fidelity based on cost, availability of suitable technologies, and training needs. It has been found that experienced pilots have a preference for high physical-fidelity environments for a number of reasons, including previous exposure to high-fidelity flight simulator devices, and concern that the performance evaluation they undergo when training, accurately reflects their real world performance (Robinson, Mania, & Perey, 2004; Turner, Turner, Dawson, & Munro, 2000). Fidelity is also a function of the degree to which the equipment and environmental cues relate to those of the real aircraft (Alessi, 1988).

There are two areas in aviation where flight simulators are mostly used; pilot training and research. The emphasis on the physical replication between simulator and aircraft in terms of cockpit layout and flight instruments is defined as equipment cue fidelity. High levels of equipment cue fidelity should result in a high degree of transfer of training to the operational environment (Rehmann, Mitman, & Reynolds, 1995). Conversely, research simulators place more emphasis on environmental cue fidelity. Environmental cues provide duplication of the operational aircraft environment and motion, and should result in a higher degree of realism being experienced by the participants. This perceived realism should result in a subject's performance matching that which would occur in the real world (Mchale, 2009).

At present, flight simulator technology is constantly evolving and the simulation industry continues to produce increased levels of physical fidelity. High levels of physical fidelity translates into higher financial operating costs and many questions still remain regarding the training benefits of using high fidelity simulators even for commercial aircrew training (Burki-Cohen, Soja, & Longridge, 1998; Dahlstrom, et al., 2009).

2.5.3 Face Fidelity

Accelerated technological developments have created six degrees of freedom (DOF) motion-based simulators with high-resolution wraparound visual systems and the exact replication and accurate functionality of every detail of the cockpit. The high degree of cockpit similarity in this type of simulator conveys a high degree of face fidelity (Arnold, 2004). Face fidelity is a measure of the how well the simulator represents the real world characteristics of an aircraft. Face fidelity is also a major factor in the acceptance of the simulator by professional pilots and with the increasing use of flight simulation, the research, and flight-training community has had some difficulty in establishing the exact levels of face fidelity necessary to meet the overall aims of simulation (Rehmann, et al., 1995; Stewart II., et al., 2008).

2.5.4 Psychological Fidelity

One major issue concerning flight simulation relates to the context in which the skills are used. Flying a real aircraft creates levels of stress and arousal that is difficult to replicate in the simulator environment. To transfer piloting skills from the simulator to the aircraft it may be necessary that the simulator also have a high level of psychological fidelity. Psychological fidelity can either be positive (e.g., motivation) or negative (e.g., fear) where both types of stress have been shown to improve training transfer from the simulator to the real world (Alexander, et al., 2005). Driskell, Johnston, Wollert and Salas (2001) tested seventy–nine US Navy School trainees in a computer training exercise under conditions of auditory distraction or time pressure. Results indicated that stress training had beneficial effects on performance and standards were maintained when trainees were faced with either a novel stressor or a novel task.

2.5.5 Motion Fidelity

The US Department of Transportation’s Volpe Centre conducted an investigation into the need for simulator motion in high fidelity simulators. In a series of joint FAA-industry symposia SMEs from industry, academia, and the FAA participated in discussions on simulator motion (FAA, 1996). The consensus was that the absence of platform motion cueing in fixed-base devices was likely to have a detrimental effect on pilot control performance, particularly in manoeuvres entailing sudden motion-onset cueing with limited visual references. It was noted that there was no scientific evidence that training in a fixed-base device would lead to degraded control performance in the actual aircraft (Longridge, Ray, Boothe, & Burki-Cohen, 1996). Moroney & Moroney (1999) found that a flight simulator with high physical fidelity on the vestibular and kinaesthetic dimensions can be expensive, and the added realism may not add to its Transfer Effectiveness Ratio (see Equation 2-2, 2-3). Other studies have produced mixed results. Burki Cohen, et al (2003a) tested pilot recurrent training performance in a FAA qualified full flight (6 DOF) motion simulator with motion switched on and switched off but did not find any significant transfer effect using motion. Burki-Cohen, et al (2003b) completed a more in-depth study on the effect of enhanced motion on airline recurrent training, pilot evaluation, and transfer of training to the full flight simulator with motion as a substitute for the aircraft (quasi-transfer). In this study, the motion platform's range of movement was enhanced in several ways. Under the enhanced motion regime, many transfer of training effects emerged.

The results indicated that although motion may not be required for recurrent training it might be required for pilot evaluation purposes. Due to the decreasing costs of high fidelity visual image generation and display equipment. US regional airlines were increasingly interested in the question of whether a FTD equipped with such a visual system (i.e., a fixed-base simulator) could be employed to fulfil the FAA requirements for recurrent training (Burki-Cohen, et al., 1998). Using full motion simulators constitutes a major training cost for such airlines. This issue was particularly relevant in relation to a device equipped with a wide field of view (FOV) visual system, which could generate an illusion of motion (Learmount, 2009; Longridge, et al., 1996). Allowing credit for the utilisation of these devices in recurrent training could reduce the cost of access, or enable the direct acquisition of this equipment by regional airlines to accomplish their own currency training (Burki-Cohen, et al., 1998).

2.5.6 Fidelity & Training Performance

To determine the relationship between level of fidelity and training performance, Jentsch and Bowers (1998) stress that simulations are best designed when only the appropriate details are embellished to increase realism. Designers must prioritise the components that need to be realistic and those that do` not, based on training requirements. Therefore, decisions about levels of physical fidelity, related costs, and training effectiveness, must be made in relation to training and real environmental elements and the logical structure of tasks. Alessi (1988) proposed that the level of fidelity on a flight simulation device should match the goals and the training stage of the learner. Fidelity is only critical in terms of how much is used in flight-simulation training and that high levels of fidelity are not required for all learners in all levels of training. Alessi also hypothesised that there existed a marginal rate of return on learning and fidelity. Increases in fidelity would provide diminishing returns in terms of training success; and differences between expert, intermediate and novice pilots must be taken into account. Expert pilots can cope better with higher levels of fidelity and achieve better learning transfer whereas novice pilots may become confused with similar levels of fidelity. The relationship between degree of fidelity and learning for novice, intermediate and expert learners is outlined in Figure 2-3.

There is a major difference in fidelity between PCATDs, FTDs, and FFSs. While the functional and physical fidelity of PCATDs is increasing steadily, there still remains a significant difference between a PC-based desktop-oriented device and a specialised, and sophisticated cockpit flight simulator (Alessandro, 2008). Hays, Jacobs, Prince & Salas (1992) indicated that positive training outcomes may be realised using simulators that do not necessarily have a high physical resemblance to the operational aircraft. The relationship between high transfer of training and high fidelity may be overstated. Improving the fidelity of PCATDs significantly may in fact overwhelm ab-initio pilots and could detract from their training effectiveness in a similar way to more advanced simulation devices (Alessi, 1988). Although high fidelity may be not necessary for ab-initio training some training difficulties had been experienced by pilots using low fidelity PCATDs.

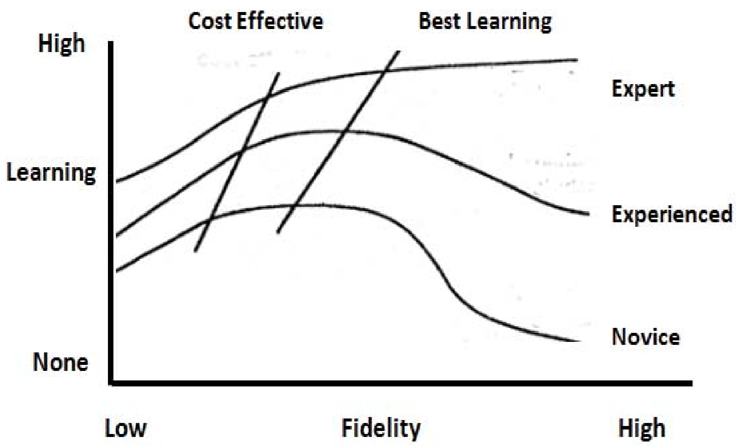

Figure 2-3. Relationship between Degree of Fidelity and Learning Stage (Facsimile)

Source: (Alessi, 1988, p. 42) - Fidelity in the Design of Instructional Simulations. *Journal of Computer-Based Instruction, 15*(2), 40-47.

Embry-Riddle Aeronautical University developed a seventy lesson integrated private/instrument curriculum for pilot training. FAA certified PCATD's and Microsoft Flight Simulator software was used to teach cognitive activities such as IFR holding patterns and approach procedures. The results indicated that PCATDs did not always match the performance characteristics of the real aircraft and poor positioning of the visual display monitors could lead to poor scanning habits (Collins, 2000). Williams (2006) emphasised the limitations with PCATD's in relation to kinaesthetic inputs and field of view. Flight control fidelity relates to the subjective feel as to how the simulated aircraft responds to the flight controls. In most cases, PCATD flight controls generally lack sensory feedback and the fidelity is rudimentary at best. Trainee pilots in an aircraft perceive inertia and movement cues through multiple senses. Also in a PCATD, due to the limited field of view, the trainee pilot may miss critical visual cues. Williams (2006) stated that these limitations could limit the effectiveness and validity of PCATDs in many aspects of VFR training. These included advanced manoeuvres such as aircraft stall and spin training where a high level of fidelity and flight modelling is required.

The first PCATDs and FTDs that were developed generally had low visual fidelity, the field of view was quite restricted, they usually displayed the front windscreen only, and the digital instruments were small (Frasca, 2006a). Consequently, compared to investigations into IFR training, few studies have examined the effectiveness of training transfer of PCATDs in relation to VFR tasks. Lintern, Koonce, Kaiser, & Morrison, (1997) established that high fidelity in terms of increasing the scene detail did not always increase training effectiveness. In fact, low fidelity scenery had greater transfer than moderate fidelity scenery and this may have been due to the reduction of visual distractions in the low fidelity scenery. Conversely, Mulder, Pleijsant, van der Vaart, & Wieringen (2000) investigated the effects of pictorial detail on the timing of the landing flare and found that that landing performance was improved when ground texture was added to the display. Roessingh (2005) investigated transfer of training of aerobatic maneuverers from PCATD to aircraft but the results only provided limited support for VFR training in the PCATD. The lack of empirical data and conclusive evidence in simulated VFR transfer of training studies coupled with the rapid developments in PCATD visual technologies indicated that this area of research would benefit from further attention.

2.6 Transfer of Training Theory

The concept of transfer of training is defined as the transfer of existing learning or skills from one learning environment to another (Roscoe & Willeges, 1980). Homan (1996) defined transfer of learning as the increase or decrease in the performance on transfer or criterion task as a function of practice or experience on a training task. In an organisational context, learning from a training experience is usually insufficient to make that training effective (Baldwin & Ford, 1988). More critical is the positive transfer of training, the extent to which the learning that results from a training experience transfers to the job and leads to positive changes in work performance. This is the main goal of organisational training efforts (Salas & Cannon-Bowers, 2001).

The use of computer-simulated training environments has increased significantly in the last decade. Recent developments in PC-based technologies have enabled the creation of realistic simulations that closely replicate the work environment. Research and development in the areas of virtual reality and simulation engines show great promise in terms of fidelity and immersiveness, and provide an indication as to how most training will be delivered in the future (Hamblin, 2005).

2.6.1 Transfer of Training Model

Transfer of training is a key issue in relation to linking an individual's performance to the operational requirements of an organisational system. If training does make a difference in organisational and individual performance, then it is vital that we understand how to support transfer of training in organisations. Baldwin and Ford (1988) defined the positive transfer of training "as the degree to which trainees effectively apply the knowledge, skills and attitudes gained in a training context to the job" (p. 63). They also noted that previous studies had estimated that only 10% of training outcomes were transferred to the workplace. In terms of flight simulator training, transfer of training involves the pilot trainee learning new knowledge, skills, attitudes (KSAs) in the simulated environment and then applying those KSAs to the operational aircraft. There is general agreement that the acquisition of KSAs is of little value if the new characteristics are not generalised to the operational setting, and are not maintained over time (Kozlowski & Farr, 1988).

Baldwin and Ford (1988), classified the factors affecting transfer of training into three categories (see Fig. 2-4):

1. Training inputs, including trainee characteristics, training design, and work environment;
2. Training outputs, consisting of learning and retention;
3. Conditions of transfer, which focus on the generalisation and maintenance of training.

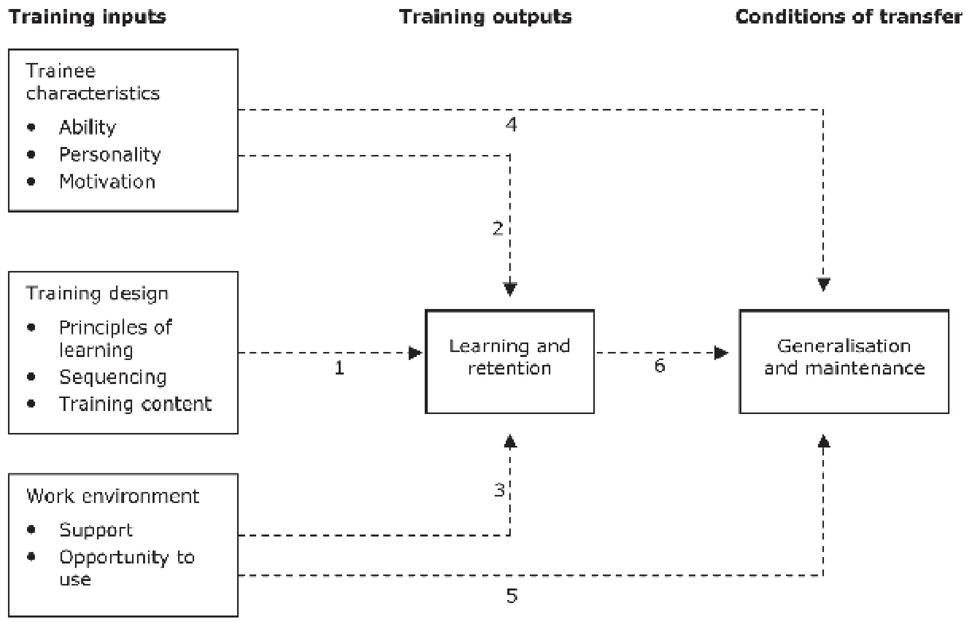

Figure 2-4. Model of Transfer Process (Facsimile)

Source: (Baldwin & Ford, 1988, p. 65) - Transfer of Training: A Review and Directions for Future Research. *Personnel Psychology, 41*, 63-105.

The conditions of transfer include both the generalisation of procedures and skills learned in training to the job context and maintenance of the procedures and skills over time on the job. Training outcomes are defined as the amount of original learning that occurs during the training programme, and the retention of that learning after the training programme is completed. The model indicates that training outcomes and inputs can affect transfer. Baldwin outlined six linkages, which describe the transfer process. Linkages 1, 2, and 3 theorise that training outcomes are directly affected by the three training inputs of training design, trainee characteristics, and the work environment characteristics. Linkage 4 and 5 theorise that trainee characteristics and work-environment characteristics have direct effects on transfer that are unrelated to learning or quality of training. Examples of this in aviation might be poor supervision by a flight captain or a lack of motivation by a newly hired pilot. Linkage 6 theorises that for trained skills to transfer, training procedures and skills must be learned and retained (Yamnill & McLean, 2001). This is the primary challenge for FTOs, to ensure that ground-training programmes such as simulation training can transfer directly to the aircraft.

2.6.2 Training Transfer Design

Training design is a major aspect of simulator training. A number of theories underpin training design and explain the conditions necessary for transfer. A theory of identical elements proposed by Thorndike & Woodworth (1901) still has relevance today. This identical elements theory postulated that transfer would occur as long as the goals, method, and approaches used for the learning task were similar to the transfer task. For example, transfer is improved by increasing the degree of correspondence among the training setting stimuli, responses, and conditions of a flight simulator and those related factors that operate in the performance setting of the aircraft. The theory outlines four types of transfer:

1. The task is identical in both training and transfer – high positive transfer;
2. The task is completely different between training and transfer – no transfer;
3. The stimuli are slightly different in training and transfer but responses are the same. The trainee can generalise from training to transfer – low, moderate, or high transfer;
4. Response to identical stimuli is different between training and transfer – negative transfer.

In terms of flight-simulation, Type 1 might represent training on a high fidelity full flight simulator and Type 3 might represent training on a low cost PCATD. Laker (1990) described transfer as *near* or *far*. Transfer is more probable with near transfer tasks, which are highly similar to the learning tasks (e.g., using a glass-cockpit FTD and flying a glass-cockpit aircraft). Transfer is less probable with far transfer, in which the tasks are different from the transfer setting (e.g., applying principles of aerodynamics to solving a serious flight-handling problem in the aircraft in a short period). Principles theory suggests that it is possible to design training environments that are not similar to the transfer situation, as long as it is possible to use underlying principles (Goldstein, 1986). In other words, if the trainees understand the underlying principles, and concepts of the skills and behaviours they are learning, the more successful the transfer.

The identical elements theory affects the acquisition of near transfer, which relates to short-term skill development. Near transfer, involves the teaching of specific behaviours and procedures, which relate closely to pilot training. In comparison, the principles theory affects the acquisition of far transfer. If trainees can apply their training to novel situations and different contexts then the more successful the far transfer (Yamnill & McLean, 2001). In addition, Gagne (1965) identified two types of generalisation processes—*lateral* and *vertical* transfer. Lateral transfer occurs when a skill encompasses a comprehensive number of situations at a similar level of complexity (e.g. applying instrument procedures to all aspects of IFR flight operations). Conversely, vertical transfer occurs when an acquired skill affects the acquisition of a more complex skill. For example, a pilot acquiring IFR/VFR skills to fly an aircraft and then having to learn crew resource management (CRM) skills for effective flight cockpit performance. Empirical research has supported the concept that similarity between training and transfer conditions is one of the more critical determinants of whether positive transfer will occur. Lintern (1991) argued there may be some limitations in this research. In particular, Baldwin & Ford’s theory does not recognise the importance of the magnitude and direction of transfer.

In addition, the understanding of task components and their transfer relationships to enable explicit prediction of transfer effects is generally not well understood. Since these early studies, transfer of training research has been characterised by inconsistent measurement and variability in findings. More positive results were obtained by Blume, Ford, Baldwin, & Huang (2010) who conducted a meta-analysis of 89 empirical studies that examined the impact of predictive factors (e.g., trainee characteristics, work environment, and training interventions) on transfer of training. The results did confirm positive relationships between transfer and predictors such as cognitive ability, conscientiousness, motivation, and a supportive work environment.

2.6.3 Motor Skill Acquisition

Skill acquisition is a significant part of pilot training. Pilot trainees must acquire and maintain practical skills, which include operating the aircraft within its limitations and completing all manoeuvres with smoothness and accuracy (Lintern, Roscoe, Koonce, & Segal, 1990).

Proctor and Dutta (1995) provided the following definition for skill as “a goal-directed, well-organised behaviour that is acquired through practice and performed with economy of effort” (p. 18). Since skills are acquired through practice, they can be trained and all skills have a perceptual, motor, and cognitive component. From an operational perspective, skills are linked with one or more tasks specific to a specific aviation task. While skills often include a knowledge component, that knowledge is tightly integrated with, and is analysed as part of the skill. An essential element in flight training and with particular relevance to simulator fidelity is motor skill acquisition. In this context, motor skills are defined as physical actions to control the work environment (Seamster, Redding, & Kaempf, 1997).

A theory of motor skill acquisition was outlined by Schmidt & Young (1986), which extended Thorndike and Woodworth’s (1901) seminal law of identical elements, and was applied to transfer investigations. The theory states that motor behaviour is guided by generalised motor programs under which motor schemas are formed for certain movements. Schemas assist in memory retention and recognition through organisation of event related information in a highly structured way. For example, the manipulation of aircraft controls is better described as a motor schema rather than a precise motor program (Rees, 1995). The theory proposes that when motor schemas are applied in highly similar circumstances, speed and accuracy will increase. Also, similarity of sequence and timing in movement between a flight simulator’s flight controls and an aircraft’s flight controls will contribute to positive transfer. If movements are not consistent in both their sequence and timing, negative transfer of training may occur. Both motor skills and motor schema are dependent on cognitive templates of what constitutes the ideal action. The motor schema that is required to manipulate the flight controls is just one of the cognitive components in the task of flying an aircraft. The trainee pilot has to establish what conditions are necessary to make their control inputs. This can only be achieved by visual reference to the outside world and enables the pilot to assess the flight control accuracy or the extent of the flight control error (Dennis & Harris, 1998).

2.6.4 Cognitive Mapping

A large body of empirical evidence supports the ability of simulations to teach skills that transfer to real-life (Cardullo, Stanco, Kelly, Houck, & Grube, 2011; Roscoe & Willeges, 1980; Rouiller & Goldstein, 2006; Salas & Cannon-Bowers, 2001; Schmidt & Young, 1986; Simon & Roscoe, 1984; Taylor, et al., 2004). Dennis & Harris (1998) suggested that psychomotor skills assist with training transfer but not as much as the generation of cognitive templates (the steps the mind rehearses when performing a task) of task experience that are practiced, experienced and applied. In Priest & Gass's (1997) model they describe the cognitive process (see Fig. 2-5):

> A simulation is first experienced when the trainee interacts with it; the trainee induces from the experience of the simulation a cognitive map of what the actual experience is; the trainee generalises that cognitive map into a permanent schema that is stored into long-term memory; the trainee then deduces from the schema acquired during training what action is required in a new situation; the trainee then proceeds to apply the action (i.e., transfers skills from training to real-life); and finally, the trainee evaluates the success or failure of that action (Hahn, 2010; p.12).

Applying this model of the experiential learning cycle to simulations reveals a process of transfer in which trainees form a cognitive map[5]. The cognitive mapping process is the

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[5] A cognitive map is a mental representation which enables an individual to acquire, code, store, recall, and decode data about the relative locations and attributes of phenomena in their spatial environment (Tolman, 1948)

basis of what makes transfer (i.e., the adaptation of skills that are applied in different or changing environments). It is not only the gaining of skills from simulations that is essential; it is also the underlying cognitive schemas the trainees create that allow them to apply and adapt those skills. This concept is called digital skills adaptability (Schaab & Dressel, 2001).

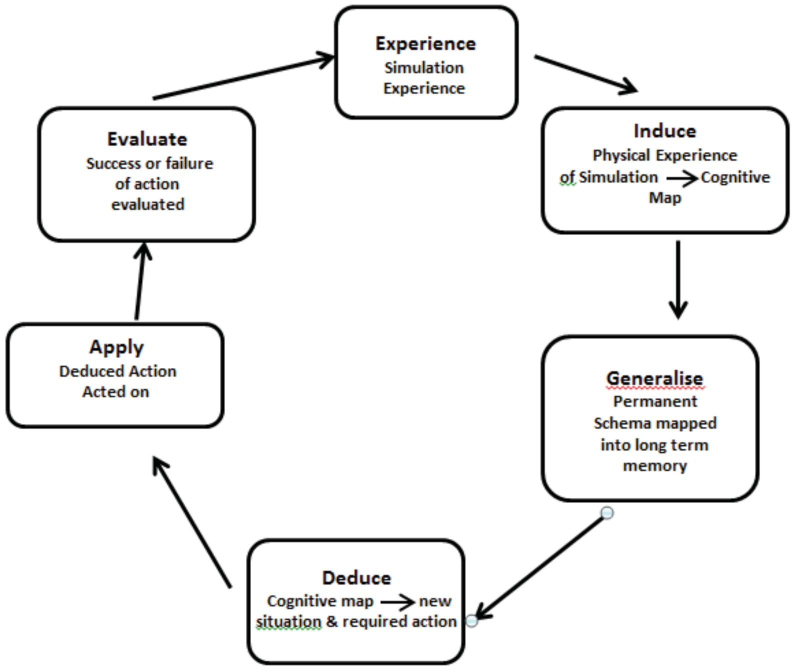

Figure 2-5. Cycle of Experiential Learning and Transfer from Simulations (Adaptation from Priest & Gass, (1997)) – Simplified Facsimile

Source: (Hahn, 2010, p. 11)-Transfer of training from simulations in civilian and military workforces: Perspectives from the current body of literature. *Unpublished manuscript*.

Digital skill adaptability is learnt through instruction on specific tasks in a way that improves the ability to transfer those skills to a broad range of new technologies. A good example of this could be using flight simulation to assist with instruction on new glass cockpit technology. It is clear that using PCATD simulation for training transfer requires the extensive application of concepts such as cognitive mapping and instructing trainees in digital skill adaptability Also, experiential learning can provide an opportunity to construct new schema from prior knowledge obtained through simulation. Empirical evidence suggests that the simulations that utilise these concepts, enhance training transfer in pilot trainees to a much greater degree compared with legacy class room delivery methods (Bill, 1999).

2.7 Assessment of Transfer of Training

2.7.1 Introduction

In aviation training, the transfer of training concept is central to the evaluation of simulator training or other devices when learning flying skills to a specified level of performance (Taylor, et al., 1999). Methods of assessing the extent of training transfer can include measuring reduction in flight training sessions, the total time necessary for training to criterion, or the number of errors while performing a flight task. For example, if a pilot trainee received a certain amount of training in a flight simulator or PCATD and was able to reach criterion performance in an aircraft in less time than another pilot who had trained only on the aircraft then a positive transfer of training from simulator to aircraft is deemed to have occurred. Alternatively, if a pilot trainee had learned ‘bad habits’ in the flight simulator or PCATD then this may require re-training in the aircraft.

If this additional training extended the time to criterion performance beyond that of a pilot trained exclusively on the aircraft, this would be a classified as negative transfer (Rantanen & Talleur, 2005). There have been several methods of assessing how much transfer of training can be achieved by using flight simulation. A quasi-transfer of training study differs from a traditional study in that a high fidelity FTD is used to test both training and transfer tasks A cost effective way is to use quasi-transfer where transfer performance is measured on a high fidelity FTD or FFS as these devices closely resemble the real aircraft environment (Atkins, Landsdowne, Pfister, & Provost, 2002). The advantage of this approach is that experiments can be highly structured and the effect of confounding variables can be reduced or even eliminated. The disadvantage is that the high fidelity device is still not the actual environment where the pilot trainee will perform the trained tasks.

Another popular method is to measure transfer of training as a factor of time saved in training the student pilot in the aircraft to a required level of proficiency by using flight simulation. This method was developed by Povenmire & Roscoe (1973) and was referred to as the Transfer Effectiveness Ratio (TER). Finally, some studies have measured performance in the aircraft which is the most difficult and expensive approach. To avoid issues with subjective measurement such as instructor bias, Roessingh (2005) introduced more precision and objective measurement into assessment of pilot performance by using flight data recording equipment installed in the aircraft to measure VFR skills performance.

2.7.2 Measurement of Transfer of Training from PCATD to Aircraft

To evaluate transfer of training, the performance of pilots trained in a FTD, and later trained to criterion in an aircraft are compared to the performances of pilots who had been trained to criterion only in the aircraft (Taylor, et al., 1999). Transfer of training can be quantified by utilising calculations involving different variables of pilot's performance. The number of training sessions, the total time necessary for training to criterion, or the number of errors while performing a task can be used to quantify the extent of transfer.

A major factor is the cost of simulator time versus the cost of actual flight time. In virtually all cases the cost of simulator time is considerably less than flight time and this has stimulated a lot of research activity on the level of training transfer that can be achieved using ground based flight simulation devices (Rantanen & Talleur, 2005; Taylor, et al., 1999; Taylor, et al., 2004). There are also several formulas for calculating the amount of transfer. The two formulas used most often in training transfer research are (Taylor, et al., 1999):

1. The Percent Transfer Ratio, which measures the ratio of time saved in simulator training relative to real-world training;

2. The Transfer Effectiveness Ratio, which measures the ratio of time saved in real-world training as a function of time spent in simulator training.

Even if the PCATD or FTD produces a positive transfer of training to the aircraft, it may do so at the cost of greater time in training. For example, flight simulator training usually requires more total training time (simulator training time plus aircraft training time) than the time required by a group that receives only training in the aircraft. Therefore positive transfer of training may also incur additional costs (Alexander, et al., 2005). Roscoe &

Willeges, (1980) described percentage of transfer formulas in more detail. The basic calculation is outlined in Equation 2-1.

$$\text{Percentage of Transfer (PT)} = \frac{Y_O - Y_X}{Y_O} * 100 \text{ ……………………..Equation (2-1)}$$

where:

Y_O = time, trials, or errors required by a control group to reach a performance criterion after no training units on a prior or interpolated task;

Y_X = time, trials, or errors required by a an experimental group to reach a performance criterion after no training units on a prior or interpolated task;

It can be deduced from this formula that this measurement is independent of the amount of time spent in the flight simulator, because the percentage of transfer calculation does not include prior practice, and it does not provide any conclusions about transfer effectiveness. Every aviation-training programme must take into account the transfer economy of a simulation-training device. To account for prior flight simulator training, Roscoe (1971, 1972, (cited in Rantanen & Talleur, 2005) developed a cumulative transfer effectiveness function (CTEF) (see Equation 2-2), and an incremental transfer effectiveness function (ITEF) (see Equation 2-3),. In the CTEF function the numerator, is calculated as the difference between the control and the training groups, divided by the total training (time or number of trials) received by the training group.

$$\text{CTEF} = \frac{Y_O - Y_X}{X} \text{……………………………………….Equation (2-2)}$$

Where

Y_O = time, trials, or errors required by a control group to reach a performance criterion after no training units on a prior or interpolated task;

Y_X = time, trials, or errors required by an experimental group to reach a performance criterion after X number of training units on a prior or interpolated task;

X = number of training units on a prior or interpolated task.

The incremental transfer effectiveness function (ITEF) (see Equation 2-3) is defined by the equation:

$$\text{ITEF} = \frac{Y_{x-\Delta x} - Y_x}{\Delta X} \quad \text{Equation (2-3)}$$

where:

Y_x = time, trials, or errors required by an experimental group to reach a performance criterion;

$Y_{x-\Delta x}$ = time, trials, or errors required by an experimental group to reach a performance criterion after $X - \Delta X$ number of training units on a prior or interpolated task;

ΔX = the incremental unit of time, trials, or errors during prior practice on a task.

The numerator ($Y_{x-\Delta x} - Y_x$) of the ITEF function is the difference in time, trials, or errors of two experimental groups to reach a performance criterion after receiving prior training. The denominator is the difference for prior training between the two experimental groups that are being compared. In addition, the ITEF formula will give the same result as the CTEF formula when comparing an experimental group with a control group. The ITEF and CTEF functions will display negatively decelerating curves or diminishing transfer effectiveness ratios as the number of trials or hours in a flight simulator increases.

Rantanen and Talleur (2005) reviewed nineteen studies conducted between 1949 and 2005 that investigated transfer of training effectiveness from ground trainers to aircraft. Earlier simulator studies were more concerned with measuring error reduction as compared to later studies that examined the saving in aircraft hours. Savings in aircraft training time was statistically significant when compared to the amount of prior simulator training but with the proviso that the average amount of prior simulator training in the reviewed studies was ten hours or less. In studies that specifically examined incremental amounts of time used in the flight simulator (Povenmire & Roscoe, 1973; Taylor et al., 2002, 2005), all produced diminishing returns in training effectiveness for additional hours. In particular, after an average of five hours of flight simulator training, additional simulator training hours produced very little advantage in terms of training effectiveness in the aircraft. In other words, increased simulator training time will increase the Percentage Transfer (PT) but will decrease the Training Effectiveness Ratio (TER). Rantanen & Talleur (2005) also found that there was little difference between VFR and IFR simulator training results. Although, in VFR flying it is considered that there are fewer procedures than IFR flying, procedural aspects of VFR flying (positioning and manoeuvring etc.) can be effectively learnt in a simulator. A pilot trainee, who has rehearsed procedures for performing certain VFR manoeuvres in the simulator, will perform better in the aircraft and will most likely master the VFR manoeuvre in less time.

2.8 PCATDs and Transfer of Training

2.8.1 Introduction

With the emergence of PC-based training devices in the early 90's, a number of studies were conducted to determine their effectiveness for VFR and IFR training (Hampton, et al., 1994; Ross & Allerton, 1991). Previous studies have demonstrated a positive training benefit from FTDs but at the time there was limited research on the effectiveness of pilot training on even lower fidelity PCATDs (Lintern, et al., 1990; Macchiarella, Arban, & Doherty, 2006; Ross & Allerton, 1991).

Before the FAA became involved in examining the effectiveness of PCATDs for training, two significant studies had supported the use of PCATDs. Pfeiffer, Horey, and Butrimas (1991) demonstrated that PCATDs could be used to reduce IFR training time by using them to perform an instrument approach task. Philips, Hulin, & Lamermayer (1993) found that student pilots who had undergone training on a PC-based instrument flight-training package exhibited a higher success rate in an aircraft than a control group using an FTD. In 1993, after extensive lobbying from the aviation training industry the FAA designated these devices as Personal Computer Aviation Training Devices (PCATD) and commissioned several major studies to investigate their viability for flight training. The FAA also reviewed about 700 completed studies, analysed the literature, and interviewed government, academic, and flight instruction experts on the use of the devices (FAA, 1999).

The overall findings from these reviews indicated that the transfer of training from PCATD to aircraft was reasonably effective, with some areas of training having higher levels of effectiveness than others. Given the positive results of the commissioned studies, and the large body of supporting research, the FAA authorised the use of up to ten hours of initial instrument training in an approved PCATD (FAA, 1997). In the past, the decision by the FAA and other regulatory authorities in granting simulator approvals was driven byte level of fidelity of the device. They now adopted a new approach in their approval of PCATD's. They began moving away from an assessment of fidelity to an assessment of the evidence that there is a positive transfer of training with these devices (FAA, 1999). Williams & Blanchard (1995) were then commissioned by the FAA to write qualification guidelines for PCATDs. Since the publication of their report, there has been continued research into the effectiveness of PCATDs for pilot training.

2.8.2 Using PCATDs with Microsoft Flight Simulator.

From the initial release of MSFS, there was a strong interest in using it for flight training (Deemer, 1997). Its versatility was quickly noticed by researchers, and the large number of transfer of training studies that incorporated the use of this software. One of the first studies combining MSFS and a PCATD was by Dunlap and Tarr (1999) who configured ten simulator workstations as Navy T-34C fixed-wing training aircraft. Fifteen scenarios were developed including familiarisation flights, basic instruments, and navigation instruments. MSFS 98 was used within an instructional programme that demonstrated each scenario and highlighted major visual and timing events. After each demonstration, student pilots were given the opportunity to practice the relevant scenario. Participants were significantly more likely to score highly during flight training and significantly less likely to fail flight training, when compared to students who did not participate.

One major limitation of the study was the absence of a control group and therefore the results have to be treated with caution. Nevertheless, a positive outcome of the study was that the US Navy developed a CD-ROM-based Naval Micro-Simulator Training Aid, which featured the instrument panel from the T-34C as well as detailed scenery from geographical areas surrounding the naval aviation training bases in Texas, and Florida. The US Navy then instituted a programme to issue the software to students at the 69 colleges and universities that host Navy Reserve Officer Training Corps units (Brewin, 2000).Williams (2006) argued that the training features of MSFS could help trainee pilots isolate tasks and divide complicated procedures into manageable components, and help instructors and students focus on specific tasks and concepts. Points 1-12 outline the main training features in MSFS that could assist with flight training:

1. Multiplayer (Aircraft): Aircraft operations can be shared with students or instructors over the Internet or Local Area Network.
2. Multiplayer (Tower): Air traffic controllers role-play for students over the Internet or Local Area Network.
3. Flights: Preconfigured flights can position a specific aircraft at a particular location, with weather, height, views, and other preset conditions.
4. Weather: Advanced weather features can create cloud layers, crosswinds, rain, and other weather settings. VFR and IFR weather minimums can be easily set to practice transition from IFR to VFR visual cues during the final stages of an approach.
5. Engine, System, and Instrument Failures: Realistic, random failures of engines, instruments, and entire flight management systems.
6. Flight Analysis: Enhanced Flight Analysis function that replicates a flight-variable data recorder (i.e., black box) in an aircraft.
7. Map View: Displays location of navigation aids, low and high- altitude airways, intersections, ground speed and track.
8. Views and Windows: Cockpit views, external views and zoomed instrument displays assist with a variety of learning scenarios.
9. Flight Videos: The flight video recorder uses VCR-like controls. The flight instructor can use this tool to review a student's flight performance in detail.
10. Autopilot: Many instrument approaches are now completed with autopilot assistance. This software device can replicate a real world aircraft autopilot.
11. Slew Mode: Slew mode is used to reposition aircraft for another landing or to enter the traffic pattern from another direction.
12. IFR Training Panels: MSFS can accurately replicate the functionality for IFR training on a range of different instrument panels.

The comprehensive range of twelve training functions listed above is similar to the functionality found in most commercial flight simulators. They provide a toolkit of software tools that enable the user to replicate the ground training environment, and training scenarios commonly found in most flight training schools (Brewin, 2000). MSFS costs slightly less than $100, and the commercial version MSFS (ESP) is about $700 which is a tiny fraction of the cost of sophisticated FTD software that normally costs hundreds of thousands of dollars (Jana, 2007). The flexibility and power of the MSFS software is testament to the extensive research and development undertaken by the Microsoft Corporation and the large number of third party companies that have supported the product by developing compatible add-on software (Garvey, 2006). This is why MSFS software originally intended for the entertainment software market has been so readily adopted by PCATD developers and flight training organisations (Williams, 2008).

Further research indicated that PCATDs installed with MSFS could possibly benefit helicopter-training providers. In Johnson & Stewart II's (2005) study, sixteen experienced and ab-initio pilots from the U.S. Army Initial Entry Rotary Wing (IERW) were recruited to evaluate a commercial PCATD, running MSFS 2000. The PCATD was used to support seventy-one flight tasks comprising the IFR/VFR Common Core helicopter-training curriculum. Pilots performed each task one or more times in the PCATD before rating it on a four-point scale. Additional data was recorded on general attitudes toward simulation and computer literacy, as well as criticisms of the PCATD. Results demonstrated a high level of correlation between the evaluations of experienced pilots and students. The results indicated that the PCATD was best at supporting IFR training, especially tasks involving radio navigation.

The perceptions made by the Army helicopter pilots were consistent with previous fixed-wing research conducted by the US Navy (Dunlap & Tarr, 1999) and other related studies (FAA, 1997; Koonce & Bramble, 1998; Ortiz, Kopp, & Willenbucher, 1995; Talleur, Taylor, Emanuel, Rantanen, & Bradshaw, 2003; Taylor, et al., 1999) that found VFR tasks from primary flight training, were not well supported by PCATDs. The most frequent comment was that the PCATD would be most valuable in training navigation instruments, and procedures. The three most frequent criticisms were related to the narrow field of view, poor visual depth cues, and difficulty in performing hovering flight tasks.

Williams (2008) argued that PCATDs utilising MSFS are better at developing pilot proficiency than flying skills, and that organisations like the FAA may be too focused on specific issues such as the fidelity of flight controls. Williams listed some strategies to utilise PC-based simulation more effectively in flight training programmes (pp. 20-28):

1. Choose a suitable aircraft - Williams argues that the simulated aircraft does not have to be an exact replica of a real world training aircraft to achieve some training benefits. Pitch + Power + Configuration = Performance, whether it is a Cessna 182 or Diamond DA 40.
2. Start in the air - Valuable training time can be saved by starting the flight in the air as most procedures can be completed in short ten-minute cycles.
3. The autopilot is a workload aid - The use of an autopilot can reduce workload in the simulator and assist students to concentrate more on operating flight controls and prioritising piloting tasks for each training scenario.
4. Fly unfamiliar Instrument Approaches – There are opportunities to fly unfamiliar Instrument approaches (IAs), standard instrument departures (SIDs), or standard instrument arrivals (STARs).
5. Tune up before real training - Practice general procedures before moving to partial panel exercises and you must include random failures and emergencies.
6. Self-critique with flight analysis - Replay flights with the flight recorder to check consistency in holding correct heading, track, and altitude.
7. Use MSFS as a teaching aid - A flight instructor can use MSFS to assess a student's pilot proficiency skills without the need to access an expensive FTD.

Beckman (2009) conducted a nationwide survey in the US to determine how MSFS was being used by pilots for both initial instrument training and for maintaining instrument proficiency. The survey was distributed via the daily electronic newsletter AvWeb, which has a subscriber list of over 200,000 pilots and other aviation professionals. All instrument-rated pilots were invited to participate in completing the survey. When 1,300 responses were received within one week of the survey publication, the survey was closed. The respondents indicated that they frequently practiced on MSFS to enhance their skills in instrument approach procedures and en-route navigation. They found this practice to be effective for both ab-initio training and for maintaining instrument currency. In addition, over 85% of pilots surveyed indicated that they use MSFS to preview approaches at unfamiliar airports, and 88% found the software package to be effective for this task. The survey also indicated that there had been a significant increase in the use of MSFS by pilots engaged in training for their instrument rating over the past 30 years. In the early 1980's, only 18% of instrument trainees used MSFS, whereas by 2009, 82% of respondents used the package during training. In addition, approximately 70% of the instrument rated pilots who responded to this survey indicated that they used MSFS to help maintain their instrument skills, and practiced on average about 5-6 hours a month. The flying tasks that trainees most often practiced included instrument approach procedures, holding patterns, basic attitude instrument flight, and en-route navigation.

2.8.3 Using PCATDs for Instrument Flight Rules Training

Before the FAA commissioned its own studies, earlier research focused specifically on PCATDs and their effectiveness in instrument flight rules training. Ortiz, Kopp, and Willenbucher (1995) investigated the effectiveness of PCATDs for training instrument flight procedures in a group of 26 pilot trainees at the Lufthansa Pilot's School. The performance of two matched groups of students was compared. One group received part of its instrument training in a PCATD while the other group received the standard course of instruction using an approved FTD. No statistically significant differences in flight performance were observed between the two groups in the final check ride but the sample size was small so the results were not conclusive. What was surprising was the cost effectiveness of the PCATD, which was developed for only three per cent of the cost of the certified FTD.

As the two major `studies commissioned by the FAA (Hampton, et al., 1994; Taylor, et al., 1996) also investigated the use of PCATDs for instrument flight training, the findings are examined here in more detail. In Hampton, et al (1994), seventy-nine students enrolled in an Instrument Flight Training Course were trained on one of three devices; the Frasca, Elite PCATD, and IFT PCATD. After their training sessions were completed, they flew in a Mooney 20J training aircraft. The flight instructors used an assessment form, based on criteria specified in the FAA's Performance Test Standards (PTS) for an Instrument Rating. The performance test standards criteria measured performance on six manoeuvres and two categories of general flight skills. Course instructors on the ground-based course and independent check pilots evaluated student performance during the ground-training phase and the in-flight portion of the course. The results of the study indicated that for the evaluated criteria there was no significant difference between students taught in any of the training devices in either the number of trials per task, or hours to achieve instrument flight proficiency in the aircraft. Due to the relatively small sample, the results must be treated with caution. The results could have been susceptible to Type II errors which are characterised by a failure to reject the false null hypothesis (Howell, 2002).

Compared to students trained on the Frasca, students trained on the PCATDs required significantly less hours and trials per task, to reach the required performance standards in the PCATDs. This may have been due primarily to ease of access and simpler operation of the PCATDs. Another significant advantage was that the cost of training in the PCATD was almost half that of the Frasca. In addition, the cost of the PCATD hardware and software was less than ten per cent of the cost of the Frasca. Due to the positive results of this study, the researchers recommended the FAA certify PCATDs to enable students to gain instrument-rating training credit.

In Taylor, et al (1996), one hundred and seven students from basic and advanced instrument courses at the University of Illinois were trained in the skills necessary for the control and manoeuvring of an aircraft solely by reference to flight instruments, including IFR departure, en route, and arrival procedures. Fifty-three students were assigned to the PCATD group, and all procedures were introduced and taught to proficiency standards in a PCATD prior to training and skill demonstration in the aircraft. For the fifty-four students in the aircraft-control group, all procedures were introduced and taught to proficiency standards in the aircraft only. Comparisons of trials to criterion in the aircraft for the two groups, the time it took to complete each flight lesson in the aircraft, and the students' course completion times were used to assess the training effectiveness of the PCATD. Twenty flight instructors were employed as both instructors and experimenters. Instructors rated student performances on instrument flying tasks in both the PCATD and the aircraft for the PCATD group; for the aircraft-control group, instructors rated student performances on the same instrument tasks only in the aircraft.

The mean trials used to compute percentage of training transfer (PT) values (see Equation 2-2,2-3) and Transfer Effectiveness Ratio (TERs) for instrument tasks ranged from a high of 33.3% to a low of 11.2%, and TERs (see Equation 2-4) ranged from a high of 0.28 to a low of 0.12. For example, one significant result was the number of trials to reach criterion on the instrument landing system (ILS) task. For the PCATD group, this required 1.5 trials in the aircraft after 2.7 prior trials in the PCATD. The aircraft-control group required 2.25 trials in the aircraft to reach the criterion. Another example is the significant difference between means and variances for total aircraft time for the aircraft control and the PCATD groups to complete the two training courses. The PCATD groups required a mean of 21/26.7 hours to finish compared to 23.1/28.18 hours for the aircraft control groups.

The results of this study indicated that the PCATD was an effective training device for teaching instrument tasks to pilot trainees. Increased values of PTs and TERs only occurred with new tasks introduced early in the training programme. There was reduced transfer of training effectiveness when the PCATD was used to review instrument tasks previously learned to a standard proficiency level. The negatively decelerated Incremental Transfer Effectiveness Rate (ITER) effect was a good predictor of reduced training transfer on review tasks but also reduced transfer of training for tasks introduced during the later stages of the training sequence. The logical explanation for this is that what is learned while mastering one task in a training device transfers to some extent to other tasks introduced later, thus reducing the remaining potential for training transfer (Taylor, et al., 1996)

Additional research into PCATDs and instrument flight training has supported the two original FAA commissioned studies. Beckman (1998) investigated the effectiveness of PCATDs for instrument training in comparison with FTDs. The study indicated that using PCATDs could present significant time and cost savings in comparison with more costly and complex FTDs. The aim of the study was to establish if there was any significant difference in training results between the two devices. Thirty-two students were split into two groups. The first group was trained on a PCATD, and the second on a FTD, before participants demonstrated their proficiency in the aircraft. Students were scored on their ability to maintain altitude, heading, assigned radial, correct time inbound, and holding patterns. Beckman's analysis found that the null hypothesis was supported, and that there was no significant difference in the transfer of training between PCATD and FTD. The scope of these findings was limited due to the small sample size (32), and the narrow range of IFR tasks (5) analysed in the study (meaning the alternative explanation of Type II errors could not be ruled out).

McDermott (2005a) also investigated the effectiveness of a PCATD for instrument training in comparison with an FTD. The quasi-transfer study did not measure subsequent performance in an aircraft but also used the FTD as the testing instrument. There were sixty-seven participants split into two training groups, a PCATD group, and a FTD-control group. A student’s IFR performance was evaluated by instructor ratings of airspeed, attitude, and altitude, intercepting the localiser and missed approach procedures.

McDermott adopted a pre-test/post-test design, which included a control group and random assignment to strengthen the statistical analysis. The tests that were performed focused on instrument landing system (ILS) proficiency as a subset of instrument proficiency. A similar result to Beckman (1998) was achieved and the null hypothesis was supported. Overall, there was no significant difference between the performances of pilots using PCATDs for training versus those using FTDs. It should be noted that the sample size was still relatively small and the results must be interpreted with some caution (i.e. vulnerable to Type II errors). Feedback from participants indicated that they strongly supported the utilisation of PCATDs for instrument approach training and maintaining currency. The participants also indicated that they believed PCATDs could improve their skills in a real aircraft.

2.8.4 Using PCATDs for Instrument Currency Training

Talleur, et al (2003) expanded on the research into the use of PCATDs for basic instrument training by also examining their effectiveness for instrument currency training. In his study, 106 instrument current pilots were divided into four groups. The pilots in each group received an instrument proficiency check (IPC 1). During a six-month period following IPC 1, the pilots in three separate groups received recurrent training in a PCATD, a Frasca FTD, or an aircraft. The fourth group was the control group and received no additional training during the six-month period. After this training period, the pilots in each group flew an instrument proficiency check (IPC 2). A comparison of performance ratings between IPC 1 and IPC 2 indicated that both the PCATD and the Frasca FTD were more effective in maintaining instrument proficiency when compared to the control group and at least as effective as the aircraft. The study also established that of the 106 instrument current pilots, only 45 initially passed IPC 1. Of the group who received an IPC in a Frasca FTD to regain currency, only 22 of 59 were proficient enough to pass IPC 1 in an aircraft. Therefore, this study established that PCATDs were effective for use in instrument currency training but were not effective in administering the IPC. Similarly, the results raised doubts about the effectiveness of the Frasca FTD in administering an IPC.

A subsequent study by Taylor, et al (2004), evaluated the effectiveness of a PCATD, an FTD, and an aircraft in conducting an instrument proficiency check (IPC). They compared the performance of three groups of 25 pilots receiving an IPC in a PCATD, in a FTD and in an aircraft (IPC 1) respectively with performance on an IPC in an aircraft (IPC 2). The IPC 1 and IPC 2 performance data was analysed to determine whether the group assignment had an effect on the pass/fail ratio and found no significant differences in performance by instrument pilots on an IPC given in either a PCATD, and FTD or an aircraft. In addition, no significant difference was found on IPC 1 among the three groups, which indicates the participants performed to a similar competency level regardless of the device in which they had the IPC. In addition, there was no significant difference on IPC 2 indicating that the device in which the participants had performed IPC 1 had no influence on their performance on IPC 2 in the aircraft. The group comparisons indicated that there was no significant difference in performance on IPC 2 between the PCATD, FTD or aircraft group. These findings support the utilisation of PCATDs to administer IPCs.

2.8.5 Using PCATDs for Ab-Initio Pilot Training

Research has also focused on ab-initio training to determine if aircraft training time to first solo, and subsequently to PPL, could be reduced by PCATD training. Dennis & Harris (1998) examined the uses of computer-based simulation in ab-initio flight training. Twenty-one participants with no flight experience were randomly allocated to one of three groups. Two groups were given training on a desktop training computer system (DTS) using MSFS software before performing basic flight manoeuvres in an aircraft. One group was able to use a set of flight controls but the other group used only the computer's cursor and function keys. The trainees were initially given one hour of basic flight instruction in the aircraft that consisted of flying straight and level at a designated speed and how to conduct coordinated medium-rate, left-hand turns. On the morning before their experimental trial flight, participants in the flight controls and keys groups were given a one-hour training session on the DTS, a third group (control) received no DTS training.

The experimental trial task was based on the "square task" used by Ortiz (1994). The participants climbed to an assigned altitude, and then they flew a straight and level leg at a speed of 80 knots for 2 minutes. They then completed a 90^{o} coordinated turn to the left, followed by a further 2 minute straight and level leg with another 90^{o} turn at the end of it. This procedure was repeated until a complete square had been flown. They found that the trainees who had completed one hour of instruction on the DTS demonstrated superior flying performance in the aircraft. They performed better in both straight and level flying and turning. The best performance was observed in the group of trainees that had prior simulation training using a representative set of flight controls, followed by the group who controlled the DTS software computer's cursor and function keys and, finally, the control group who had no DTS training.

The results indicated that the type of control interface on a DTS did not influence subsequent performance in flight, although the DTS had some positive training benefit. A higher fidelity control interface had some performance benefits but it was not statistically significant. The advantage of the DTS seemed to be that it provided a cognitive template of what the task looked like rather than in psychomotor skill acquisition. An additional finding was that students with prior training on the DTS who used the representative flight controls also experienced lower in-flight workload in the aircraft. However, the sample was very small for each group and the students only performed extremely simple flight tasks. Although the results were interesting they were not conclusive and an evaluation of more complex tasks would need to be undertaken was very small for each group and the students only performed extremely simple flight.

Vadern, Westerlund, Koonce, & Lewandowski (1998) used a PCATD to train sixty three ab-initio flight students. Thirty-nine foreign airline trainees and twenty-four students from the US participated in approximately 10 hours of basic VFR training between the completion of their ground school course work and flight lessons. All PCATD training followed a strict syllabus of training. After the completion of their PCATD training, students completed the traditional flight lesson syllabus and training performance was recorded up to private pilot (PPL) certification. Dual flight hours prior to the first solo flight, landings prior to the first solo flight, dual flight hours between the first solo flight and private certification, and landings between the first solo flight and private certification provided dependent variables for this study. The results of the study indicated that the PCATD training was effective in improving training performance for some students. Those students who exhibited the greatest improvement usually required more training prior to solo and private certification than the syllabus of training allowed for. Results also indicated that the PCATD training had the greatest impact on training performance prior to solo.

Another study used a FTD as an integral part of the training curriculum. Macchiarella, et al (2006) initiated an eighteen month longitudinal study following the performance of ab-initio pilots up to PPL certification. The researchers examined the skill transfer from a Frasca 172 FTD to a single engine aircraft used for training ab-initio pilots. This study differed somewhat from previous transfer of training studies due to its utilisation of a modified curriculum with a greater emphasis on simulation training. The study used 38 volunteers: 18 were assigned to an all-flight control group, and 20 were assigned to an experimental group that used the modified FTD and aircraft flight-training curriculum.

The experimental curriculum contained 60% simulated flight and 40% aircraft flight for approximately 70 hours of flight training. Students successfully training with this experimental curriculum completed 28 hours of flight training in the real aircraft and the remainder in the FTD. The control group's curriculum was comprised of 70 hours of aircraft flight. The FTDs were used primarily for training VFR tasks. There were 34 training tasks recorded in the study including manoeuvres such as taxiing, steep turns, crosswind landings, and power-off stall. For the experimental group, 33 of the 34 tasks demonstrated positive transfer from FTD to aircraft, which was significantly better than the control group in 18 out of 34 tasks. Tasks that were performed in close proximity to the detailed 3D imagery of the FTD achieved higher levels of transfer when compared to those practiced in lower fidelity areas of the virtual scenery. A high level of physical fidelity of the cockpit was also advantageous in procedural task training and demonstrated a positive transfer.

2.8.6 Using PCATDs for Visual Flight Rules Training

One of the first studies that investigated the use of PCATDs for visual flight rules training was Lintern, et al (1990). Ab-initio students enrolled in the flight-training programme were given landing practice training in a simulator utilising a computer-generated runway landing display before they commenced intensive landing practice in the aircraft. The experimental group received two sessions of simulator training prior to flight training whereas a control group received no simulator training. The experimental student group and control student group were paired with the same instructor. The study demonstrated that simulator trained students required less pre-solo landings in the aircraft than did their paired control group students. This represented a saving of 1.5 pre-solo flight hours per student. The experimental results indicated that pre-training with a moderately detailed, low cost, computer-generated landing display could offer savings in flight time. In addition, some students in the experimental group were provided with adaptive visual augmentation displays during their simulator training, and there was evidence of positive incremental training transfer.

Schneider, Greene, Levi, and Jeffery (2001), in a United States Air Force (USAF) study performed a controlled experiment comparing standard flight instruction to standard flight instruction plus PCATD practice. They compared the flight training performance of 55 students who were provided with access to PCATDs with that of 209 students who only received standard flight training. The two groups were compared on their learning of nine advanced VFR flight manoeuvres such as a loop and barrel roll. There were two measures of trials to criterion for each task and two measures of variability for each task. The results indicated the PCATD group performance was statistically significant in one measure only.

Nevertheless, the PCATD group demonstrated much less variability than the control group, which is meaningful, as advanced VFR manoeuvres must be performed consistently with minimal variation for safety reasons.

Roessingh (2005) extended the previous study by investigating the transfer of manual flying skills from PC-based simulation to actual flight. He also compared in-flight measured data (objective measure) using a flight data recorder with flight instructor ratings. In this research, he investigated learning profiles of pilot trainees who practiced aerobatic manoeuvres in an aircraft under the supervision of a qualified flight instructor. The aim of each pilot trainee was to fly five aerobatic manoeuvres (the loop, the slow roll, inverted flight, the Immelmann, and the split-S) in a fixed-order continuous sequence.

The skill level of each trainee was assessed by the accuracy of each manoeuvre flown, during ten flight lessons of 30 minutes. A learning curve was generated by plotting the skill level (accuracy expressed as a performance score) against the number of practice hours in the aircraft. Trainees were assigned to three different groups. A control group was not given any simulator training prior to flight training and testing. A second group was trained on a standard PC-based simulator containing a software package that could be used to practice simulated acrobatic manoeuvres. Finally, the third group was trained on a PC-based simulator that was equipped with additional features. A basic cockpit and realistic flight controls (control stick, rudder pedals, and throttle. The enhanced simulator also provided automatic instructional feedback in the form of text messages on the computer screen, directional symbols, and a performance rating. The aircraft in-flight data were measured and recorded with customised PC-based equipment.

This equipment measured altitude, indicated air speed, three axis orientation angles, three axis angular rates, three linear accelerations and type of manoeuvre. The in-flight performance data was analysed by the instructors after the experiment and they rated the trainee's performance during the flight. After analysis of the flight profiles of 189 flight lessons, all trainees exhibited an increase in their comparable level of skill at the aerobatic manoeuvres. Despite almost 500 minutes of additional ground simulator training no significant increase or decrease in manual flying skills was attributable to the skills that were acquired with the simulator on the ground. Flight instructor evaluations had initially indicated a positive transfer from the simulation lessons with the PC simulation incorporating additional features but this was later discounted due to differences in instructor rating behaviour. In conclusion, there was neither negative transfer nor positive transfer of manual flying skills learned during the simulation lessons. A small advantage of the PC-based simulation was that the pilot trainees required less briefing time with the flight instructor after every 50 minutes of simulation.

Roessingh (2005) reasoned that the results of this study might be because transfer of training effects may have to be calculated at a lower level of task performance. The pilot trainee's skill level was measured by an aggregate performance score based on 25 criteria. A more detailed analysis of the flight data recordings could reveal positive transfer component skills and negative transfer for other component skills with the net result being zero training transfer. In addition, the fidelity of the simulator used in this experiment compared with those used in studies that found a positive transfer-of-training effect might have been markedly different.

A later study by Rogers, Boquet, Howell, & DeJohn (2009) recruited two groups of participants who were given simulator-based training in upset-recovery manoeuvres . One group were trained in a high fidelity centrifuge-based FTD and the other group used a desktop computer running MSFS. A third group (control) received no upset-recovery training at all. Twenty-eight participants were selected for the simulator training groups and thirty participants for the control group. All three groups were then subjected to in-flight upsets in an aerobatic aircraft. Pilots from both trained groups significantly outperformed the control group in upset-recovery manoeuvring in the aircraft. In addition, there was little performance difference between pilots from the two-trained groups. The relatively low number of participants has meant that Type II errors cannot be ruled out.

2.8.7 Using PCATDs for Crew Resource Management Training

The forerunner of Crew Resource Management (CRM) was team training and this is an integral component of aviation training. Team training is necessary when participants have (Brannick, Prince, & Salas, 2005, p.174):

1. specialised roles, skills and responsibilities;
2. require extensive training;
3. work in an advanced tchnological environment;
4. and perform interdependent tasks that require intensive communication and coordination.

Flight crews of commercial and military aircraft are highly specialised teams and team training for these crews was originally called cockpit resource management but is now designated as crew resource management (CRM) (Brannick, et al., 2005). Although CRM is widely practiced in military and civilian aviation there is little empirical evidence to support its use that comes from training evaluations (Prince & Salas, 1999). In addition, few studies have evaluated the transfer of training of CRM skills utilising a PCATD.

The FAA advisory circular on CRM training specified three critical components of CRM training: Initial indoctrination/Awareness, Recurrent Practice/Feedback, and Continuing Reinforcement (FAA, 2004). There is now more emphasis placed on the behavioural basis for effective CRM rather than attitude or personality. The FAA directive also stated that CRM training must be included as a regular part of the recurrent flight-training requirement. However, it is unrealistic to expect short training programmes to reverse years of bad habits and behaviours. To be effective, CRM has to be embedded in every stage of training, and CRM concepts should be particularly emphasised in flight line operations. This new philosophy moves the focus on the phases of CRM training from the awareness phase (where attitude change has been targeted) to continuous practice and feedback (FAA, 2004). Although CRM training programmes have existed for more than a decade, methods for providing aircrew with opportunities to practice CRM skills have been limited to role-play in class and scenarios in FTDs (Helmreich, Merritt, & Wilhelm, 1999).

There are disadvantages to both training methods; role-plays have few realistic environmental cues to help crews behave as they do in the cockpit, and simulator scenarios are limited by the cost and availability of the simulators (Brannick, et al., 2005). One study circumvented the high cost of using a flight simulator for CRM training by substituting it for a desktop computer system with MSFS. Baker, Prince, Shrestha, Oser, & Salas (1993) studied the acceptance of the Navy's Table-Top Aircrew Coordination Training System (TTACTS), which utilised MSFS V4.0. Two decision-making scenarios were given to one hundred and twelve pilots and aircrew who participated in aircrew-coordination training session. After flying the scenarios in teams of two, the participants were asked to indicate their acceptance of the system on a 5-point Likert scale. Over 90% of the participants agreed that TTACTS was useful for CRM training. In addition, there was reported feedback that the aircrew were impressed with the realism of the simulations with respect to the behaviours that the scenarios elicited.

Jentsch & Bowers (1998) found fifty commercial pilots elicited similar responses to CRM training and evaluation in a PC-based simulation using MSFS 5.1. These results lend further support to the premise that aviators from military and commercial backgrounds find low-fidelity simulations PCATDs suitable for CRM training.

Finally, Brannick. et al (2005) conducted a study to demonstrate positive quasi-transfer of CRM behaviours learned in a PC-based system to the cockpit of a high fidelity, full-motion simulator. A PCATD was used to develop a crew resource management (CRM) training module. Two-person teams practiced with the PCATD and received feedback from an instructor about their performance. Training effectiveness was evaluated by comparing trained teams (N = 24) to control teams (N = 24) in a high-fidelity simulator. Raters who were blind to the experimental conditions provided evaluations of the teams on both CRM and technical proficiency. The results indicated a positive transfer of training of CRM skills from the PCATD-based system to the high-fidelity FTD, thus supporting the utilisation of relatively inexpensive PC-based systems for CRM training.

2.8.8 Using PCATDs for Scenario Based Training

Coupled with an increased demand for general aviation aircraft, has been the increased deployment of glass-cockpit technically advanced aircraft (TAA) (Craig, Bertrand, Gosset, & Thorsby, 2005). A TAA can be defined as any aircraft with an advanced flight management navigation system that links a global positioning satellite (GPS) with an autopilot (French, 2005). Digital microprocessor controlled instruments represent a significant advance in avionics capability over the traditional, pressure driven analog instruments that are found in most legacy GA aircraft. Usually the TAA consists of two displays; a primary flight display (PFD) that displays the flight characteristics of the aircraft (e.g., heading, altitude, and attitude), and the multifunctional flight display (MFD) that usually displays engine performance data, fuel state, and a moving map navigational aid (Smith, 2008).

In partnership with industry and academia, the FAA/Industry Training Standards (FITS) programme created scenario-based, learner-focused training materials that encourage practical application of knowledge and skills (FAA FITS, 2012). The goal of the programme is to assist pilots training in or operating TAA's. These aircraft commonly have advanced glass cockpit systems with more automation and greater performance capability. The FITS programme, enables pilots to develop the risk management skills and in-depth systems knowledge required to safely operate and maximise the capability of these aircraft (FAA FITS, 2012). In addition, FITS syllabi have been developed by drawing from military, academic and industry training programmes.

These syllabi identify skills and training standards required for most types of pilot training, from ab-initio general aviation aircraft to very light-jet (VLC) aircraft (FAA, 2006). Legacy IFR & VFR training utilises a skill and task based approach. Pilots are trained on particular manoeuvres to acquire skills to a level of ability that almost provides automatic responses to external stimuli. This is called Manoeuvres Based Training (MBT) and there has been criticism that skills acquired over many years of this type of training may have drifted towards a practice of teaching to the flight test (IFALPA, 2012). In addition, skills tend to be learned in isolation. For example, pilots learn specific manoeuvres like forced landing rather than linking that training with a scenario where it might arise during flight.

With traditional training methods, the student mimics the manoeuvres demonstrated by the instructor until accomplishing it successfully (FAA, 2012b). The student is passive in this process and does not easily develop the ability to identify and correct weaknesses. The FITS programme has developed the Scenario Based Training (SBT) system to address these deficiencies (French, 2005). Scenario-based training (SBT) is a training system that uses a highly structured programme of real-world experiences to address flight-evaluation in an operational environment (FAA FITS, 2012). The concept is based on the premise of training the way you fly and flying the way you train. The FITS programme places more emphasis on whole task training and uses carefully planned scenarios structured to address TAA flight-training objectives in a real world operational environment. Scenarios give the pilot an opportunity to practice for situations that require sound aeronautical decision-making.

The FITS curriculum guides also require that scenarios be adapted to the flight characteristics of the specific aircraft and the likely flight environment, and that they require the pilot to make real-time decisions in a realistic setting (FAA, 2006). SBT thus provides an effective method for the development of judgment and decision-making skills. Ideally, all flight training should include some degree of scenario-based training, which helps develop decision-making, risk management, and single pilot resource management skills (FAA FITS, 2012). The aim of SBT is to produce the correct response when a situation requires a specific manoeuvre. If the pilot has already practiced the manoeuvre in a similar scenario he or she is more to likely to respond appropriately when faced with it in the aircraft (Kasemtanakul, 2009). The SBT pilot usually responds faster than the MBT pilot, who has to search his or her memory to link a manoeuvre to a real life scenario. This is the underlying theme of SBT, to give the learner opportunities to acquire knowledge and skills necessary for correct task performance via simulated “real-world” operational scenarios (FAA FITS, 2012). Active learning, extensive practice and feedback are the mainstays of SBT, and these are also the characteristics that distinguish SBT from other training methods (Salas & Cannon-Bowers, 2001). Kasemtanakul (2009) compared the procedural-ATD lessons (FITS, 2004) with the FAA’s instrument training task requirements list for PCATDs. He established that there were 11 SBT lessons, where PCATDs could be fully used to train the whole lesson to the student. Because the physical tasks and equipment are more complex in TAA’s, the need for the integration of cognitive and physical skills also increases (FAA, 1999). Kasemtanakul made two recommendations for the effective use of PCATDs for SBT:

1. A PCATD could be used for the introduction of aircraft systems and basic aircraft maneuvers before the beginning of each FTD session.

2. A flight instructor should be used to provide proper instruction to trainee pilots at the beginning of PCATD training, especially ab initio pilots (Kasemtanakul, 2009 p. 12).

2.8.9 Using PCATDs and Negative Transfer of Training Effects

Negative transfer is defined as learning that can interfere with task performance instead of improving it (Martin, 1981). For trainee pilots many aspects of flying an aircraft are first learned on a PCATD. Self-directed learning with PCATDs without the support of a certified flight instructor and formal flight training in an aircraft can sometimes be counterproductive. Due to concerns raised about fidelity of flight controls, aircraft handling and visual flight training, Alessandro (2008) suggested that PCATDs may be detrimental for ab-initio training as essential psychomotor skills may need to be relearned.

Negative transfer could possibly occur when a replica instrument or switch is not identical to the one in the aircraft or is placed in a different position in a PCATD instrument panel (FAA, 1999). For example, if a pilot trains in a plane with the retractable landing gear switch on the left side of the cockpit and the flap switch on the right and then flies an aircraft with switches reversed, confusion can arise which might jeopardise safety. Also, issues with the fidelity of flight controls of a simulator in relation to the real aircraft could also lead to negative transfer (Johnson & Stewart II, 2005). Nevertheless, most aviation-training experts did not believe that the issue of a PCATDs similarity to the aircraft presented major safety issues (Dennis & Harris, 1998; Koonce & Bramble, 1998).

Many approved FTD"s and PCATDs do not typically represent one particular type of aircraft and often include generic instrument panels that differ from those on the aircraft in which the student will train (FITS, 2004; Redbird, 2010). Embry Riddle University in conjunction with NASA's Advanced General Aviation Transportation Experiments (AGATE) programme developed a private/instrument curriculum that used a combination of FTDs, PCATDs, and aircraft for training (AGATE, 1996). FAA-certified PCATDs and off-the-shelf software such as MSFS were restricted to teaching cognitive activities such as holding patterns and approach procedures, where they could provide practical experience, practice, and reinforcement. The university relied heavily on PCATDs during the first private/instrument class, and did experience some negative transfer. For example, the PC performance of the flight model did not always match that of the actual aircraft, especially during slow manoeuvres and stalls. Also, there were limitations in the visual display system, and if the monitor was not properly sized and positioned, it could lead to poor scanning habits. Despite these limitations the PCATD based curriculum had strong advantages for training in TAA's and the university's goal using AGATE was to reduce overall training time by 25 per cent (Collins, 2000).

Williams (2006) discussed negative transfer and the formation of bad habits. While working in the aviation training industry he noticed a general concern among flight instructors about bad habits that can form from using PCATDs. These habits are generally exhibited in the areas of incorrect flight control inputs, poor understanding of systems and procedures, and inadequate performance of basic tasks. One common example of poor habit formation is instrument panel fixation. Trainee pilots who use PCATDs for self-directed learning tend to fixate on the instruments and avoid scanning outside the aircraft. This is also an airmanship issue and may require corrective training to relearn visual flight scanning and situational awareness (Alessandro, 2008). Nevertheless, Williams counters these criticisms with the fact that virtual PCATD aviators generally make faster progress in training than trainees with no previous aviation experience.

Homan (1998) argued that a structured and professionally designed programme under the close supervision of a certified flight instructor is critical to the success of flight training using PCATDs. It was more likely that a student will play with a PC-based trainer than with a more expensive FTD. Game playing usually results in unstructured and often *fighter pilot* types of flying activity. When these flight activities are practised repeatedly, they become an integral part of the students' flying repertoire, and could become ingrained. Unlearning ingrained techniques is a difficult task and should be avoided as much as possible. In critical situations, trainee pilots tend to repeat initial training manoeuvres that were self-learned or first taught to them. If pre-training involves gaming with PC-based programs like MSFS this could cause negative transfer.

Despite the risks, Homan is optimistic and outlines some positive attributes for PCATD training. Real-flight problems such as relinquishing too much control to the autopilot could be addressed by pre-programmed autopilot failures on the PCATD. With the availability of photorealistic graphics, and full horizon displays, conflicting air traffic and Controlled Flight into Terrain (CFIT) scenarios could also be realistically practised on the PCATD.

2.8.10 Using PCATDs for Classroom Instruction

There has been a dramatic increase in the complexity of aviation training in the last decade but the aviation education process in the classroom has not similarly evolved (Fryer, 2012). The ground school lecture or mass brief usually consists of a lecture, enhanced with numerous PowerPoint slides, followed by a discussion, and then at the end of the course, a written examination. The trainee pilot is expected to retain this classroom knowledge until it is applied sometime in the future during flight training (FAA, 2012a). This traditional teaching process is appropriate for visual and auditory learners but not for kinaesthetic learners who need to apply the knowledge directly in practical situations in order to retain it (Pashler, McDaniel, Rohrer, & Bjork, 2009). Two technologies that can be successfully incorporated into classroom instruction are Computer-Based Training (CBT) programs and PCATD simulation. These training tools can be utilised for pre-class preparation, as well as post-class review and reinforcement. CBT programs also assist the student in achieving self-paced learning (Bedwell & Salas, 2010).

A PCATD is a low cost classroom aid that can provide a realistic simulation of procedural flight training. In addition, PCATDs can be effectively integrated into the training curriculum and provide a bridge between the traditional aviation classroom and the advanced aviation flight environment (Karp, 1996). Williams (2006) argued that PCATDs should not only be used as cockpit trainers, but also be utilised in more interactive and focused training contexts, including the classroom. PCATDs can be used for one-on-one instruction or in small or large classroom contexts with the simulator visuals projected onto a large screen. Examples of the use of PCATDs as a classroom training aid include demonstration or presentation of:

1. specific equipment, procedures, and tasks;
2. flight instruments and effects in context;
3. flight controls / surfaces and effects in context;

4. navigation concepts and practice;
5. various flight scenarios with discussion of cause and effect;
6. pre-flight and post-flight briefings;
7. advanced situational awareness training in aircrew flight training programmes.

Moroney & Moroney (1991, cited in (Koonce & Bramble, 1998), utilised two CBT software packages, MSFS and Aircraft and Scenery Design (ASD) for classroom instruction. The software was utilised as an aid in academic classes on human factors in aviation, for psychology and engineering students. The students learned about the software capabilities, the principles and difficulties involved with performance measurement, and the construction of PCATD features to enhance training goals.

Galvin Flying Service at Boeing Field in Seattle was one of a growing number of flight schools using MSFS within their training curriculum (Collins, 2000). Galvin had installed Garmin GNS 430 GPS receivers in its Cessna 172 fleet, and employed Garmin simulation software as well as flight-planning software. Galvin's training facility was then upgraded with a computer lab, local area network and internet access. The flight department manager, an early adopter of this technology expected increased use of simulations in training. He stated:

> In the multimedia classroom, you can bring MSFS up on the projector, and fly it down the localiser on the autopilot. You can put in wind and other variables, all in a controlled environment, Can we create training programmes that use low-cost tools and give good results, and train instructors to use them? My sense is the answer is yes (Collins, 2000, pg. 1).

The latest version, FSX is well suited for use in classroom instruction and CBT training. It contains 12 interactive tutorials and approximately 40 more advanced missions (rated beginner, intermediate, expert) that can be utilised for classroom instruction. Some of the tutorials include First Take-off, Basics of Flight, Ground Operations, and Approaching the Airport. Missions include accurate simulations of many real world international instrument approaches (Microsoft, 2010). In addition, the commercial release of FSX mission design software such as Flight1 Aviation Technologies Scenario Builder has enabled the rapid prototyping of custom designed interactive tutorials and missions (Flight 1 Aviation Technologies, 2012a). A number of these packages have been developed by the researcher for user testing and feedback before eventual release into the aviation training community.

2.9 Conclusions

The utilisation of relatively low cost PCATDs for flight training has become increasingly popular in the last decade. PCATD software capabilities continue to improve exponentially and hardware configurations are now more closely representative of the cockpit or flight deck of a real aircraft. Therefore, the PCATD has become a useful tool for presenting high quality representations of aircraft performance and instrumentation (McDermott, 2005). The development of PCATDs has provided low cost training alternatives to more expensive FTDs and FFSs. Nevertheless, constraints in low cost development have meant compromises had to be made in areas of fidelity such as cockpit and instrument panel replication, graphic display realism and flight control dynamic loading technologies (Bechtold, 2008)

Commissioned research into the effectiveness of PCATDs for flight training by the FAA culminated in the issue of an Advisory Circular, AC61-126 which approved the limited use of special personal computers, controls, and software called ”personal computer-based aviation training devices (PCATDs)” for up to ten hours of instrument training. To qualify as an FAA-approved PCATD the device had to provide “a training platform for at least the procedural aspects of flight relating to an instrument training curriculum” (FAA, 1997, p.1). The achievement of this significant milestone, required major support from aviation training providers and substantive research had to be completed by academic institutions (Hampton, et al., 1994; Taylor, et al., 1996).

Many of the limitations in research on PCATDs discussed in the literature review were clearly identified by the FAA in 1997. They include small experimental samples, narrow focus (e.g., very few VFR transfer of training studies have been completed), and a range of fidelity issues Most of the transfers of training studies completed in the last decade have had modest sample sizes (less than 100 participants). This has meant that statistical power has been low thus the results are vulnerable to Type II errors (Howell, 2002). Another difficulty with these types of studies has been the high cost and complex coordination associated with using aircraft and high fidelity FTDS as research tools. One strategy that researchers have adopted to reduce costs and complexity in their experiments is to use a quasi-transfer methodology.

Quasi-transfer can use high fidelity flight simulators or FTDs for training and testing of transfer of training as these devices are a close representation of the aircraft (Taylor, Lintern, & Koonce, 1993). Although there is some inherent risk with the approach as no matter how high the physical fidelity level of the simulator it cannot replicate entirely the aerodynamic forces that act on an aircraft in the real world. Nevertheless, due to recent technological advancements such as low cost multi-view graphic processors (Nvidia, 2010), and hydraulic joysticks (Paccus, 2012) the difference between the fidelity of PCATDs. FTDs and FFSs are narrowing rapidly.

Most PCATD construction is characterised by a combination of proprietary and COTS hardware and software components. This modular design means PCATDs can be developed with a high degree of customisation. Many PCATDs have been developed by non-traditional manufacturers such as hobbyists, military flight training units, aero clubs, research laboratories, and university based aviation schools. Constant evaluation and feedback by end users (e.g., pilot trainees & flight instructors) is an essential feature of this type of PCATD development. Unlike proprietary FFSs and FTDs, PCATDs can be quickly modified and components can be upgraded relatively easily. For example, in Johnson & Stewart II's (2005) study, the utility of a PCATD for primary helicopter training was assessed by intensive task and heuristic evaluations conducted by pilot trainees and flight instructors. The results indicated a high level of agreement in identifying training tasks that could be transferred from the helicopter to the PCATD.

In relation to the overall deployment of PCATDs, there are still areas where more substantive research is required. These areas include the utilisation of PCATDs in Visual Flight Rules training, self-directed learning, ab-initio training, CRM training, glass cockpit training, and classroom instruction. More research is also required in determining how PCATDs can be integrated into a modern flight-training curriculum. Flight instructors need to be more proactive in discovering new ways that PCATDs can help them with flight instruction especially for ab-initio students. There has also been an increased emphasis on fidelity and the rapid adoption of new technologies in relation to PCATDs.

Nevertheless, more research is required into how PCATD training programmes relate to learning styles, the evaluation of learning transfer, and learning outcomes. The use of PCATDs is now well established in the aviation-training environment but the devices still tend to have limited roles in most pilot training programmes. Many PCATDs are being under-utilised and can easily be adapted to assist with a range of ancillary flight training activities. These activities include classroom instruction, CRM training, and SBT. Future development of new technologies should increase the training capability of PCATDs but substantive research is required on how to integrate them more effectively into the flight-training curriculum.

Chapter 3. Flight Training In New Zealand

3.1 Introduction

Most pilot training in New Zealand (NZ), up to and including the Commercial Pilot's Licence is completed in flight training schools, and this forms the basis of professional development for airline pilots as well as other pilots involved in commercial aviation (CAANZ, 2012). Evidence suggests that a major factor in the quality of these professional pilots is related to the quality of their early flight training (Aerosafe, 2011). Most of the flight schools in NZ are relatively small operations that struggle to provide quality flight training at an affordable cost (Aerosafe, 2011). PCATDs are a valuable resource that can support the procedural aspects of flight training operations (Landsberg, 1997). A training aid that can reduce aircraft hours may be beneficial to the pilot trainee in terms of both training efficiency, and reduction in the cost of training. For example when completing an instrument rating, twenty hours of aircraft training time can be completed in a CAANZ certified FTD or PCATD (CAANZ, 2011d). Ready access to a certified simulator is also an excellent marketing tool for flight schools and these devices enhance safety because students can gain proficiency before attempting flight manoeuvres or procedures in the aircraft (Frasca, 2012b). Unfortunately, many flight schools in NZ cannot afford a high fidelity certified FTD so the development of low cost PCATDs is one solution that could partially solve this issue (Landsberg, 1997).

New Zealand's varied geography and weather, and its extensive areas of uncontrolled airspace, create an advantageously unrivalled environment for pilot training (Castalia Srategic Advisors, 2011). There has been unprecedented growth of the local aviation industry in the last two decades. The NZ aviation sector in 2009 was estimated at $9.7 billion in revenue, and was expected to grow between 5-9% per annum (Castalia Srategic Advisors, 2011). A strong focus on aviation safety has produced pilot training organisations with high levels of instructional capability and expertise (Aerosafe, 2011). New Zealand also has good infrastructure particularly in an efficient air-traffic control system, robust educational institutions, affordable rental housing, economical transport, and modern information systems (Castalia Srategic Advisors, 2011).

Because of these advantages, NZ can provide flight training at a much lower cost than most other countries (NZTE, 2010). This has made it an attractive training base for potential airline pilots from Asia and the Middle East. Many of these pilot trainees after graduating, find aviation related jobs in NZ, and make a significant contribution to the aviation industry and the NZ economy (NZTE, 2010). Flight training in NZ is a diverse industry. It includes recreational activities such as gliding and microlights as well as advanced flight training such as the commercial pilot's licence and instrument ratings. Flight training is provided by flying schools and aero clubs registered with the New Zealand Qualifications Authority (NZQA) and approved under Part 61 (Pilot Licences & Ratings) and/or Part 141 (Training Organisation Certification) by the New Zealand Civil Aviation Authority (CAANZ, 2011b, 2011e). Students receiving flight training offered by approved flying schools and aero clubs are eligible for student loans if the courses are offered in conjunction with a tertiary education institution (TEC, 2012). A number of tertiary education institutions offer diplomas, degrees, and post-graduate degrees in aviation-related subjects. Massey University is the only university in NZ that has a flight-training programme within its aviation degree programme (Massey Aviation, 2012). All organisations approved for student loans are members of the Aviation Industry Association (AIA), and follow the association's code of practice for professional flight training (AIANZ, 2011).

Flying Schools are established to provide professional flight training, and employ experienced flight instructors and provide comprehensive facilities for training including classrooms, flight simulators, and aircraft. Services offered by flying schools range from novice level training for microlight certificates and private pilot licenses, commercial pilot licenses, and more comprehensive training for instrument, instructor, and multi-engine ratings, and more specialised instruction (e.g. mountain flying, handling of dangerous goods, and GPS navigation) (NZS, 2008). Some schools also offer NZQA accredited aviation diplomas. Aero Clubs have moved beyond the traditional format of amateur flying operations undertaken on a rudimentary grass strip, and are now subject to comprehensive CAA regulations for flight training, aircraft maintenance and training facilities (CAANZ, 2011b). In 2008, five tertiary education institutions, eighteen flying schools, and forty one aero clubs were NZ Aviation Industry Association (AIA) members (NZS, 2008).

3.2 Part 61 vs. Part 141 Flight Training Schools

There are two types of flight training school in NZ. Those who train pilots under CAANZ Part 141 regulations and those who train pilots under CAANZ Part 61 regulations (CAANZ, 2011b, 2011e). Most Part 141 training organisations are well established with comprehensive flight simulation resources. The more numerous Part 61 flight training schools are generally smaller and have very few flight simulation resources. The development of low cost PCATDs has great potential for the smaller Part 61 schools as their training programmes would benefit most from this type of training technology. A Part 141 school has two distinct advantages over a Part 61 school. It can internally assess its students and the students can complete fewer hours than required towards certain licences and ratings. However, Part 141 certification is difficult to achieve and a flight school must meet stringent requirements and submit each curriculum of training for approval by CAANZ. Part 141 schools are also subject to regular audits by CAANZ and must achieve specified pass rates on the practical exams (CAANZ, 2011b). Table 3-1 lists some other advantages and disadvantages of training in Part 61 and Part 141 schools (Wallace, 2010).

Table 3-1. Part 61 vs. Part 141 Schools

CAANZ Regulation	Advantages	Disadvantages
Part 61 School	More flexible training	Less structured environment
	More suitable for part time students	Some students may require more remedial training
	Students can interview and choose his/her flight instructor	Less flight instructors to choose from at a particular airport
Part 141 School	A structured programme with flight instructors and ground instructors	Students can be overwhelmed by pace of programme
	Suits full time career-oriented students	Little choice in assigned flight instructor
	Students can complete less hours for licences and ratings	School located at a major airport so student may have to relocate

Source: (Wallace, 2010)- Part 61 vs. Part 141. Retrieved from http://www.flyingmag.com/pilot-technique/new-pilots/flight-school-part-61-or-part-141

3.3 Demand for Flight Training in NZ

Due to high costs of acquisition, many NZ flight schools do not have any certified FFSs or FTDs in their training inventory. However, the acquisition and use of relatively low cost. PCATDs is steadily increasing (Massey News, 2008). The demand for PCATDs is directly linked to increased flight training activity in NZ. In 2000, there were 98,000 training hours with a steady increase to 198,639 hours in 2009. In 2000, 9.9% of the total hours were attributed to helicopter training. In 2009, this figure had increased to 11.3% (Aerosafe, 2011). Table 3-2 shows the total number of lifetime pilot licences issued in NZ of each type (Air Transport Pilot's Licence, Commercial Pilot's Licence, & Private Pilot's Licence) plus the total number that have an active class 1 or class 2 medical (CAANZ, 2012).

Table 3-2. Pilot License Statistics

Licence Type	Total Number	Active
ATPLA Part 61 PL (Aircraft)	3381	2004
ATPLH Part 61 PL (Helicopter)	163	192
CPLA Part 61 PL (Aircraft)	6127	3380
CPLH Part 61 PL (Helicopter)	1991	1289
PPLA Part 61 PL (Aircraft)	10417	2954
PPLH Part 61 PL (Helicopter)	1209	503

Source: (CAANZ, 2012)- Pilot License Statistics. Retrieved from http://www.caa.govt.nz/Script/PilotLicStats.asp

The prime source of new pilots for commercial operations is from a 'pool' of those trained in New Zealand. There are three training paths to becoming a commercial pilot. These are (Frampton & Walkington, 2011):

1. A tertiary degree (3-4 years) , or diploma (2-3 years);
2. An aero club or flight training school, which offers flexible courses.

Most NZ pilot trainees seek financial assistance from the Tertiary Education Commission (TEC) to help pay for their flight training (TEC, 2012). Student loans are only available for the degree or diploma training paths and training institutions. Each training institution is given a quota of the number of Equivalent Full Time Students (EFTS) they can train that will receive full student loan funding. An average of 3.46 EFTS in training is required to deliver each commercial pilot over the mix of training paths. Successful completion is classified as a student graduating with the relevant degree or diploma along with a CPL (Frampton & Walkington, 2011).

In 2012, there was an estimated aviation industry requirement in NZ for two hundred and ninety-nine new fixed-wing CPLs and seventy-nine new helicopter CPLs (Twentyman, 2012).. In the same year, TEC only provided enough student loan funding to train 30% of the total requirement of potential pilots needed, and this level of funding has slipped further behind the CPL training requirement for 2013 and beyond (TEC, 2012). This has caused growing concern within the NZ aviation industry that the current rate of graduating pilots will not meet long-term demand, with major airlines around the world placing orders for new aircraft at record levels. Adding to that is the recent recruitment drive for pilots by Air New Zealand both here and in Australia and the picture becomes more concerning.

This shortfall in government funding has meant that many pilot trainees may be forced to self-fund their flight training in the near future. This in turn will place more pressure on flight schools to find ways to reduce the cost of their flight training programmes (Van Den bergh, 2011). One strategy is to reduce the number of aircraft hours to the regulatory minimums and increase the number of training hours in PCATDs or FTDs. The acquisition of low cost PCATDs and FTDs could very well determine the economic survival of small flight training schools in NZ.

3.4 Multi Crew Pilot License Training

One strategy that may reduce the impact of pilot shortages in NZ is the accelerated introduction of the Multi Crew Licence that also emphasises *intensive flight simulator training* and drastically reduces the number of flying hours in the aircraft. In 2006, a new pilot qualification was established by the International Civil Aviation Organisation

(ICAO). The MPL was designed to develop the abilities of pilots to fly multi-crew airline aircraft. Compared to traditional training pathways (e.g., CPL & ATPL) it makes greater use of flight simulators, adopts competency-based-training methods and emphasises human factors and threat and error management in all phases of training (Sheck, 2006). One of the only ‘hours’ stipulations in a MPL is a minimum total of 240 instructional hours, which is a total product of actual flight and flight simulation time. Actual flight time in an aircraft can vary from 80 to 112 hours. This means that MPL trainees could spend up to 50% of their training time in an approved flight simulator (IATA, 2011).

The main philosophy of MPL is to limit trainee exposure to actual flight in non-relevant light aircraft and the bulk of instructional time is then transferred to multi-crew flight simulation. Almost 200 MPL pilots are now flying with airlines, and 2,000 MPL students were in training by the end of 2011 (Bent, 2011). CASA approved the introduction of the MPL in Australia in 2008 (CASA, 2008). In 2009, CAANZ formed an issue assessment group (IAG) on the introduction of the MPL but four years later have still not promulgated an implementation date (CAANZ, 2009).

3.5 Flight Training Utilising Synthetic Flight Training Devices

The value of synthetic[6] flight training devices (SFTDs) is in their effectiveness when used for training IFR/VFR procedures. The average number of hours spent in training for a Private Pilot’s Licence (PPL) is between sixty and sixty five hours. The minimum CAA Part 61 requirement is fifty hours or forty hours without cross-country training. (CAANZ, 2011e). The average number of hours spent in training for an instrument rating is between sixty to seventy hours. The minimum CAA Part 61 requirement is forty hours of instrument time where twenty hours can be completed in an approved SFTD (CAANZ, 2011d). Any type of simulation device that can reduce the requirement for more aircraft Using SFTDs should result in a reduction of costs for pilot trainees, and their respective flight schools (Massey News, 2008).By using SFTDs, students can also increase self-guided practice of some tasks and maneuvers thereby improving their skills and

[6] CASA used a new term to describe PCATDs and FTDs when it released its FSD 2 Approval procedures for new flight simulation devices (CASA, 2002)

proficiency (Ace's Pilot Shop, 2012). An examination of SFTD ownership in Australia, New Zealand and the USA indicates that use of these devices is increasing (BestAviation.net, 2012; Wiggins, Hampton, Morin, Larssen, & Troncoso, 2002). In particular there has been rapid growth in the number of PCATDs used by flight training schools primarily because of the decreasing costs and increasing capabilities of these devices

3.5.1 Utilisation of FTDs & PCATDs in the USA

A survey of 354 flight-training organizations in the USA was conducted to identify what training devices were being used in their respective flight training programmes (Wiggins, et al., 2002). The results of the survey indicated that 381 FTDs, 224 PCATDs, and 99 other types of training aids[7] (OTAs) were being used in PPL and CPL programmes, instrument, and multi-engine rating programmes. Other pertinent information gleaned from the survey indicated that:

1. University programmes used these devices more than Part141 or Part 61 schools.
2. FTDs still outnumber the other devices, most were certified by the FAA, and were primarily used for instrument rating training.
3. Most of the training organisations used more than one type of training device.
4. Microsoft Flight Simulator was an extremely popular OTA in the university programmes (71) compared to Part 141 schools (1) and Part 61 schools (2).

Of the 354 schools that responded to the survey, 327 reported on the number of enrolled student pilots. The average number of students enrolled in universities was 171.8; Part 141 schools had an average current enrollment of 61.3 student pilots. Part 61 schools had an average current enrollment of 39.5 student pilots. Forty-seven universities, fifty-one Part 141 schools, and four Part 61 schools reported using PCATDs. Universities were the largest users with an average of 1.3 devices per school. Part 141 schools averaged 0.4 devices per

[7] These include aids such as MSFS software and CBT CD-ROM software (Wiggins, et al., 2002)

school whereas Part 61 schools averaged 0.3 devices per school (Wiggins, et al., 2002). The survey indicated that many U.S. flight schools were using various flight training simulators and computer programs to reduce flight time in the air. By using FTDs and PCATDs, flight training can be completed more quickly, and the flight school achieves increased control over the training environment. University based training centres tend to use flight simulation in their programmes more than other flight training schools. They reported an average of 78.0% of their students use them whereas Part 141 and Part 61 schools reported averages of 61.3% and 39.5%, respectively. By way of comparison Massey University is the only NZ university, (also Part 141 certified) that has an aviation-training programme. It also has a higher usage rate of FTDs and PCATDs than other equivalent Part 141 and Part 61 schools in NZ (Massey News, 2007, 2008).

3.5.2 Utilisation of FTDs & PCATDs in Australia

With large areas of undeveloped land, a scattered population, and a limited infrastructure, aviation services are more critical in Australia than most other countries in the world. The need for timely medical evacuation, package delivery, livestock herding, and standard passenger and cargo carriage has created a very active professional aviation community. The aviation sector contributes AUD 32.0 billion (2.6%) to the Australian GDP and supports 312,000 jobs (Oxford Economics, 2011). To satisfy the demand for trained aircrew in Australia, there are sixty-seven flight training schools (fixed wing) and twenty-six helicopter training schools. There are also four comprehensive university based flight training programmes; University of New South Wales, Swinburne University of Technology, University of South Australia, and Griffiths University (BestAviation.net, 2012). Thirty Australian flight training schools (31%) advertise that they incorporate FTDs and/or PCATDs in their flight training programmes (BestAviation.net, 2012). Table 3-3 lists a small sample of Australian flight schools that have similar FTDs and PCATDs found in NZ flight training schools. Australian flight training schools that do incorporate flight simulators into their training programmes generally use a wide range of devices. In a similar way to NZ flight schools most (69%) of them do not utilise any FTDs or PCATDs in their respective flight training programmes, although they are probably being used for informal training and individual practice. This makes it difficult to quantify the impact these devices have, on today’s flight-training environment.

Table 3-3. Sample of Australian FTOs with FTDs & PCATDs

Flight Training School	Type	Manufacturer-Model	Training Aircraft
Airborne Aviation	PCATD	Elite AT-21	Cessna 172 S, Cessna 172 R, Cessna 172 G, Cessna 182 T, Cessna 152 Aerobat, Cessna 310 R, Piper Tomahawk, Piper Seneca II, Beechcraft Duke, Beechcraft Debonair
Basair Aviation College	FTD	Frasca 242	Cessna 152, Cessna 172, Cessna 182, Tecnam 2002JF, TB10 Tobago, P28A Warrior, BE24 Sierra, PA30 Twin Comanche
	PCATD	Red-Bird Motion Simulator	
Melbourne Flight Training	FTD	ELITE IGATE S623	Cessna 152, Piper PA28 Warrior II, Piper PA28R Arrow IV, Cessna 172R Skyhawk, Cessna 182T &182S Skylane, Piper PA34 Seneca, Beechcraft BE95 Travelair, Piper PA44 Seminole, Partenavia PN68
Moorabbin Flying Services	PCATD	Elite IGATE S623	PA28 Warrior III, PA28 Archer III, PA44 Seminole
Royal Queensland Aero Club –partnered with Griffiths University	FTD	AST-300	Cessna 152, Cessna 172, Cessna 172RG, Cessna 206
Western Australian Aviation College	FTD	Frasca 142	Piper Seminole, Partenavia PN68, Mooney, Cessna 152, Cessna 172, Cessna 172 RG

Source: (BestAviation.net, 2012) Aviation Schools in Australia. Retrieved from http://www.bestaviation.net/australia/

3.5.3 Utilisation of Synthetic Flight Training Devices in NZ

There is little consolidated information about the type of training devices being used in NZ flight schools. Although some information can be obtained from relevant websites. It is unclear how many PCATDs are used in formal training programmes, or informally by students. A detailed survey of flight simulation devices currently being used in NZ FTOs has not been completed.

3.5.3.1 Full Flight Simulators

The most sophisticated FFSs are wholly owned and operated by the national flag carrier and its subsidiaries. Air New Zealand is the largest airline in the country and has a suite of seven full flight simulators (see Table 3-4). The 747 and 767 simulators are over twenty years old and have limited visual display systems. There has been a gradual replacement programme of older simulators but a new Boeing 787 simulator scheduled to arrive in 2012 is now delayed until the arrival of the aircraft in 2014 (AIRNZ, 2008). All the flight simulators are utilised for continuous conversion and recency training. A discussion with the Technical Director of the AIRNZ Flight Simulator Centre indicated that the centre required thirteen technical staff and one engineer to maintain the simulators, and the average cost to operate each simulator is approximately $US 400 per hour. Approximately 860 Air NZ pilots complete recency training annually (P. Burr, personal communication, 14 May 2012).

Table 3-4. Full Flight Simulators operated by NZ FTOs.

Simulator	Type	Manufacturer	Motion Axes	Qualification Level	Operator
Airbus 320-232	FFS	CAE NZ 32 (Certified 2003)	6	ICAO Level II JAR-Level D	Air NZ
B747-400	FFS	Rediffusion 5158 (certified 1989)	6	CAP 37 Level 5	Air NZ
B767-219	FFS	Rediffusion 7250 (Certified 1985)	6	CAP 37 Level 4	Air NZ
Bombardier Q100/Q300 Dash 8	FFS	Flight Safety International (certified 2005)	6	JAR -Level D	AirNZ
B777-300ER	FFS	CAE 2FT9-903 (certified 2010)	6	ICAO Level II	AirNZ
B737-300/400/500	FFS	CAE 2R66-337 (Certified 2001)	6	CAANZ ICAO II	AirNZ
ATR 72-500	FTD	Mechtronix (certified 2010)	Fixed	NZ CAA CAT II	Mt Cook Airlines
737-800NG	FTD	Pacific Sim	Fixed	CAANZ-IRT	Pacific Sim

Source: (ANZAI, 2012) - Air New Zealand Aviation Institute: http://www.aviationinstitute.co.nz/ai/school-of-flight/professional-crew-training/flight-simulators/

Despite the complexity and the realism of the full flight simulators available to Air NZ pilots, some of them still utilise programs such as FSX or FS2004 for informal training on a laptop or home computer. They also used quite sophisticated software (MSFS compatible) such as Precision Manuals Development Group (PDMG) Boeing 737NGX & Boeing 747-8IF (PDMG, 2012) (S. Hall, personal communication, July 12, 2009). Pacific Simulators based in Christchurch, NZ has developed the first NZ manufactured Boeing 737-800 NG FTD (Fixed Base) at a fraction of the cost of a full motion full flight simulator. The company has sold an FTD to Dubai Aerospace Enterprise Flight Academy (DAEFA). DAEFA Head of Training, Captain Richard Morris indicated that the device provided the ideal environment for systems, procedural and multi-crew training and was a lead-in trainer for the full flight simulator (Fairfax, 2008).

3.5.4 `Utilisation of FTDs & PCATDs in NZ Flight Training Schools

A significant number of NZ flight training schools still do not have CAANZ certified FTDs or PCATDs in their inventory. Nevertheless, many have access to non-certified PCATDs or Part Task Trainers. These devices commonly use MSFS or X-Planes, installed on a desktop/laptop and usually include rudimentary flight controls (Joystick, Throttle, and Rudder). A survey was required to establish the scale of the need for affordable flight training devices in NZ and the potential benefits that might accrue if these were available. This survey sought information on the type of training devices being used in NZ, and the number of FTOs currently using them. Also, how devices are being used, and whether those FTOs who do not have any devices, intend to purchase one in the near future.

Chapter 4. Methodology

4.1 Action Research

The research presented in this thesis is based on the development of low cost flight simulation devices, which were tested, evaluated, and modified in an iterative process. This type of research process or design is best described by an action research model. This section defines the principles of action research and the rationale for its use in this study. Action research is a well-established research method used in the social and medical sciences since the mid-twentieth century (McNiff & Whitehead, 2010). Kurt Lewin, the founder of action research, described action research as "a spiral of steps, each of which is composed of a circle of planning, action and fact finding about the result of the action" (Lewin, 1949).

In the 1990s, action research began to be used in scientific investigations of information systems. The method produced relevant research results, because it was grounded in practical action and aimed at solving an immediate problem situation. One of the key characteristics that distinguishes action research from most other research approaches is that action research aims at both improving the subject of the study (the research client), and generating knowledge, achieving both simultaneously at the same time (O'Brien, 2001). The domain of the action research method is characterised by a setting where:

1. the researcher is actively involved, with expected benefit for both researcher and organisation;
2. the knowledge obtained can be immediately applied, there is not the sense of the detached observer, but that of an active participant wishing to utilise any new knowledge based on an explicit, clear conceptual framework;
3. the research is a cyclical process linking theory and practice (Baskerville, 1999; Baskerville & Wood-Harper, 1996).

Some of the main characteristics of action research are that it is (McNiff & Whitehead, 2010):

1. practice based, where practice is both action and research;
2. about improving practice (both action and research) creating knowledge, and developing living theories of practice;
3. focused on improving learning and not just on improving behaviours;
4. about research and knowledge creation and is more than just professional practice;
5. collaborative and focuses on the co-creation of knowledge practices.

The most prevalent action research, details a five-phase cyclical process. The approach first requires the establishment of a client-system infrastructure or research environment (see Fig. 4-1). Then, five identifiable phases are iterated:

1. diagnosing;
2. action planning;
3. action taking;
4. evaluating;
5. specifying learning.

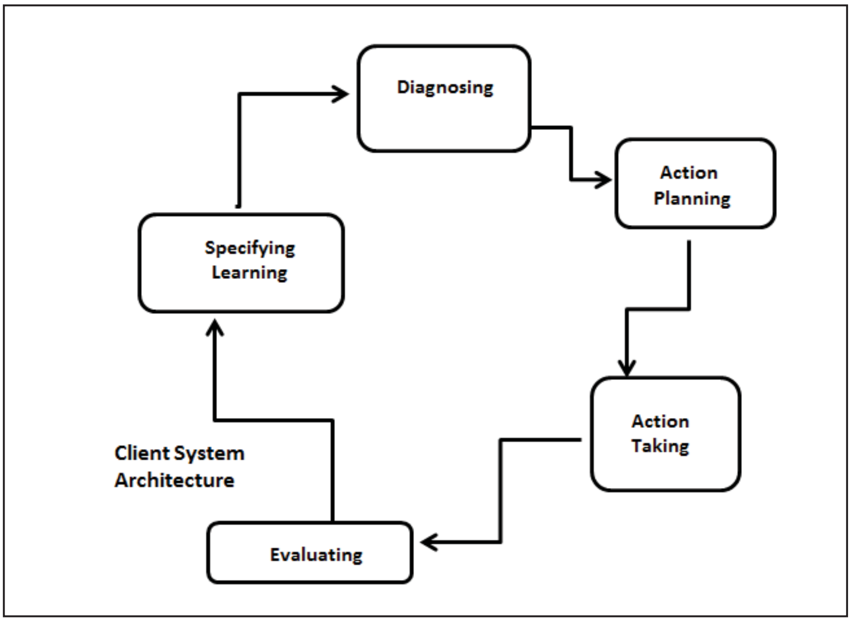

Figure 4-1: The Action Research Cycle (Facsimile)

Source: (Baskerville, 1999) Investigating Information Systems with Action Research http://dl.acm.org/citation.cfm?id=374476

The client-system infrastructure is the specification that comprises the research environment. It provides the authority for researchers and practitioners to specify certain actions. The agreement may include the boundaries of the research domain, and the entry and exit of the researchers. It may also allow researchers to disseminate the learning that is gained in the research. The infrastructure should also define the responsibilities of the client and the researchers to one another (Baskerville, 1999). The diagnosing stage, where the cycle begins, involves the identification of an opportunity to improve a process or service or a general problem to be solved at the client organisation. The following stage, action planning, involves the consideration of alternative courses of action to achieve the specified improvement or solve the problem. The action taking stage involves the selection and implementation of one of the courses of action considered previously. The evaluating stage involves the study of possible outcomes of the selected course of action. Finally, the specifying learning stage involves reviewing the outcomes of the evaluating stage and, then utilising this knowledge to construct a model that describes the experimental situation (Koch, 2011).

Technological development has no value without action, and action research encompasses action. Human-computer interaction (HCI) technologies have had a significant impact on modern society and research on HCI has increased worldwide since the 1990s. This has included Internet and Web-based HCI technologies, and personal computer applications. In technology-related research, an action research study could involve the researcher introducing a new technology into an organisation, and simultaneously studying the effects of the technology in that organisation. The expansion of HCI research has coincided with the increasing use of action research in the study of technology-related issues (Koch, 2011).

Information systems prototyping (ISP) has been recently associated with action research despite an absence of theory in its development (Chiasson & Dexter, 2001). The ISP method is defined as an effective information system, and in involving the researcher in a collaborative and facilitative iterative, rigorous, and collaborative/facilitative method. It supports iterative cycles through a precise set of steps in developing process with participants. Depending on the particular ISP method used, these rigorous steps include an iteration between risk analysis, prototype, software requirements, requirements validation, and further development plan (Chiasson & Dexter, 2001).

4.2 Simulation Design

The Action Research model lends itself to the design of simulation undertaken in this study as the simulation design process follows a similar five-cycle process (Wieringa, 2012). The steps are:

1. Problem investigation;
2. Treatment design;
3. Design validation;
4. Treatment implementation;
5. Implementation evaluation.

In addition, while completing this process of simulation design, the researcher plays three roles:

1. Designer- Designs a system or technique;
2. Helper - Uses the system or technique to help others;
3. Researcher- Draws lessons learned about system or technique.

Simulation is an essential component of aerospace research and design. Its ability to predict complex system behaviour makes it valuable for the analysis and testing of many entities, including vehicles, on-board components such as pilot-interactive systems such as cockpit displays, flight control systems, and flight procedures. Flight simulation can artificially recreate many of these entities combined with the various aspects of the flight environment (Ippolito & Pritchett, 2000). Simulation can fit into all stages of research and design. During basic research and conceptual design, low and medium fidelity simulations can highlight fundamental problems or issues and constraints on the system design. As the design progresses, higher-fidelity models can be added to the system so that its output provides detailed feedback for designers (Ippolito & Pritchett, 2000). Fritz, Gray, and Flanagan (2007) proposed that simulation designers have to consider three levels of fidelity: environmental, equipment, and psychological. Environmental fidelity ensures that task content is realistic; equipment fidelity ensures that the selected hardware and software is similar to real life; and psychological fidelity ensures that the students have a sense of real immersion when participating in the simulation.

A central characteristic of current flight simulator design is that it incorporates technology standards and COTS hardware and software, which is cost effective (Elite, 2012d; PFC, 2004). Twenty years ago, flight simulators and desktop trainers were proprietary, expensive, and designed in-house with custom components and proprietary databases (Adams, 2008). Utilising COTS technology not only provides potentially high levels of fidelity but also lowers the cost of the system because of the availability of open source or standard software (Meyer, 2010). Today's systems can replicate very realistic and complex weather patterns, vehicle and aircraft movements, and terrain due to commercially available tools and commercial standards (Mchale, 2009).

Nevertheless, some interface software is not be available as COTS and requires in- house development. The development of flight simulation software can take significant time and resources, to the extent that 'rapid' development has been described as that achievable in weeks or even months. In addition, if there is a lack of resources to develop a customised software package then common practice is to re-use already-existing flight simulation software. Existing components can then be modified, and existing flight simulators may have new components added to provide new functionality (Ippolito & Pritchett, 2000).

This thesis reports a survey and five action research cycles. The survey involved the collection of survey data to ascertain the current utilisation and future demand of PCATDs in NZ flight training organisations. The following five cycles comprised the development of five PCATD projects. The projects were characterised by the adoption of the action research philosophy that emphasised close collaboration with the host organisations who were involved with the projects. The development process was an iterative one whereby knowledge gained on each project was utilised in subsequent projects in a process of continuous improvement. Although these projects seem diverse, they had common characteristics that linked them closely within the action research cycle, these common characteristics included:

1. High risk, as they combined newly released PC-based technologies together with untested software packages (both commercial and open-source) with uncertainty regarding the ultimate success of the project. In all cases, the projects required additional development of hardware and software interfaces that did not exist commercially or as open source. In addition, these interfaces had to be developed with software tools that were mostly beta versions and therefore lacked official support by their authors. This adoption of this difficult approach was driven by the need to constrain or reduce costs and to avoid the necessity of using expensive proprietary hardware and software.
2. All projects used a common software simulator platform, MSFS. Although, the projects did use different versions of the software depending on project requirements. These different versions were regularly upgraded as Microsoft released updates but retained compatibility with earlier versions.
3. Common hardware and software modules for flight controls and avionics were used in several projects.
4. In all projects, there was an emphasis on developing high-resolution visual displays of out- of- the- cockpit- views with a strong intent to improve visual fidelity.
5. All projects involved close collaboration with senior pilots, flight instructors, and pilot trainees. Evaluation and feedback was sought on the IFR/VFR task training effectiveness of the respective PCATDs. In addition, collaboration and assistance was sought on the development of a PCATD training programme, insertion into the training curriculum, and PCATD training documentation.
6. External validation in the form of NZ Civil Aviation Authority IFR/VFR certification was achieved in two of the projects.
7. Internal validity was sought by an empirical comparative study of one of the PCATDs with a certified FTD to ascertain if the training effectiveness of the PCATD was similar to a certified FTD. In this case, the effect of PCATD training on performance improvement in VFR skills was investigated, due to the lack of substantive research in this area.

The projects included:

1. A Survey of NZ Flight Training Organisations in NZ was conducted to establish how many flight-training organisations in NZ were using Full Flight Simulators (FFs), Flight Training Devices (FTDs); Personal Computer based Aviation Training Devices (PCATDs) and Part Task Trainers (PTTs) in flight training programmes. The aim of the survey was to establish commercial and training opportunities in relation to this research and to establish if there was a demand for low cost PCATDs in NZ based flight training schools. A number of questions were presented to these organisations, to ascertain their current flight simulation inventory, how they were using these devices in their flight training organisation, their level of interest in acquiring an aviation training device, and their future intentions regarding these devices.

2. RNZAF Pilot Training Squadron (PTS) PCATD Project. These PCATDs were the first prototypes to be developed in NZ for ab-initio IFR/VFR skills training of military pilot trainees.

3. Auckland Rescue Helicopter Trust (ARHT) PCATD Project. This PCATD demonstrated the effectiveness of a low cost PCATD for visual flight rules and instrument flight rules helicopter flight training.

    a. TracMap GPS Project Extension. This software/hardware interface was the first to be developed in the world as an extension of the ARHT PCATD project. It demonstrated the effectiveness of a low cost PCATD for training visual flight rules search and rescue procedures in conjunction with the TracMap Search and Rescue GPS (Aerial Survey & Search Pattern) unit.

4. Massey University School of Aviation SAV1 PCATD Project. These two PCATDs were the first to be developed in NZ that were designed specifically for VFR skills training, and incorporated multi-display technologies.

a. New Zealand Army Unmanned Aerial Systems (UAV/UAS) Operators Flight Training Project Extension. This project was an extension of the Massey University School of Aviation SAV1 PCATD project as it used an identical flight simulation system. The development of these multi-purpose PCATDs demonstrated the effectiveness of low cost PCATDs for solo rehearsal of VFR procedures towards PPL.

5. Massey University School of Aviation SAV2 PCATD Project. This PCATD demonstrated the effectiveness of low cost PCATD VFR training and used LCD multi-display technologies. Empirical research was conducted on this PCATD to compare its VFR task training effectiveness with a certified FTD.

6. Massey School of Aviation Diamond DA 40 PCATD Project. This PCATD demonstrated the effectiveness of low cost PCATDs for visual flight rules flight training and instrument flight rules training. Also this PCATD was the first device developed in NZ to simulate the Garmin 1000 glass cockpit flight deck combined coupled with a 2 DOF motion platform. This PCATD is also being utilised as a research vehicle for studies on general aviation glass-cockpit automation, scenario based flight training and simulator motion.

The purpose of this research was to evaluate the benefits and cost effectiveness of using a customised PCATD to improve pilot proficiency in performing VFR procedures. Five PCATDs were developed for use in pilot training programmes conducted by flying training organisations. These devices were developed as training aids to assist those organisations in improving the transfer of learning in flight training. This study focuses on the development of these PCATDs and in particular, an empirical study of the transfer of training effectiveness of a PCATD designed specifically for VFR procedural training. The cost of this VFR procedure PCATD represents only a fraction of the financial capital required to purchase a commercially available CAANZ certified FTD. Evidence of the effectiveness of the PCATD in pilot training was determined from comparative studies in two of the research cycles:

- A quantitative analysis on the relative effectiveness of a PCATD compared to a CAANZ certified FTD for improving pilot proficiency in the performance of a standard VFR traffic pattern operation

- An additional analysis was completed to compare the performance of a standard VFR traffic pattern operation by two groups of pilot trainees with different levels of aviation experience on the same PCATD. The level of proficiency required for the execution of these VFR manoeuvres was based on the performance standards outlined in the syllabus of training of the CAA AC61-3 Private Pilot Licenses (CAANZ, 2011e).

4.3 Research Questions

The thesis investigates three critical questions:

1. Can a low cost PCATD be as effective as a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation?
2. Is there a significant difference in performance of a standard VFR traffic pattern operation on a low cost PCATD between pilots from two different flying training organisations and with different levels of aviation experience?
3. Can low cost PCATDs achieve the fidelity and conformity required for CAANZ certification in VFR and IFR procedures training?

Chapter 5. Survey of NZ Flight Training Organisations

5.1 Introduction

A survey was conducted to ascertain which FTOs in NZ were using flight simulation devices and how they were being used in their flight training programmes (see Appendix C). The purpose of the survey was to answer four key questions:

1. What was the current status of flight simulation devices in NZ in terms of distribution, cost, type of device available, and utilisation in flight training organisations?
2. Were the existing flight simulation devices being used effective?
3. Was the use of PCATDs increasing and did the aviation training community consider these devices to be effective for IFR/VFR flight training?
4. Could a low cost PCATD, customised for NZ flight training conditions assist those FTOs with no flight simulation devices in their inventory?

This was a snapshot in time, as flight simulation technologies were improving rapidly during the survey period, and many flight schools were preparing to upgrade obsolete equipment or contemplating the purchase of new flight simulation equipment. Virtually all flight simulators being used in NZ were sourced from well established companies based overseas (Adams, 2008). Due to NZ's isolation, and the relatively weak NZ dollar, the cost of purchasing and shipping a certified FTD from overseas was high compared to Australia and the U.S. Therefore, ownership of FTDs has been, in most cases, restricted to the large well-funded flight schools. The survey also recorded the emergence and impact on flight training of low cost PCATDs at NZ flight schools, which is a relatively new phenomenon.

5.2 Methodology

Initially one hundred and twenty aviation organisations in NZ were identified as potential targets for a survey (see Appendix D). Apart from a few exceptions, the commercial flying organisations involved in aviation activities such as charter work, tourism, and search and rescue did not have fully structured internships or training programmes. They were front line operations who hired experienced pilots as required and most training was focused on maintaining pilot currency. From the initial list, seventy-two aviation organisations were classified as having a flight training function, which extended beyond operational requirements such as maintaining pilot currency. Seventeen of these flying training organisations did not reply to the survey. These non-responders had a similar structure, they were all small aero clubs situated in rural areas and were not fully manned during normal work hours. The primary focus of these small FTOs was recreational flying which occurred mainly after hours, and on weekends. Because these FTOs had very small numbers of full time students, the lack of meaningful data from them, had a negligible effect on the survey results (NZTE, 2010).

Another issue when conducting the survey was that many FTOs had different departments within their infrastructure: a training academy section, a recreational flying section, and sometimes even a small commercial charter section. A good example of this was the Canterbury Aero Club that was also affiliated with the International Air Academy of NZ. Although the affiliate was situated nearby, it was a separate and distinct legal entity. In terms of practical training, the two FTOs often shared the same resources such as buildings, aircraft, and instructors.

Eventually the list was reduced to forty distinct training organisations or entities that were positively identified as having a sustained and viable flight-training programme. The flight-training curriculum usually consisted of primary and/or advanced flight training as well as fulfilling professional and currency training requirements. The survey was conducted over a three-month period. The results of the survey indicated that the forty flight training organisations were training approximately 1300-1350 student pilots a year. It was difficult to ascertain the exact number of international students in this group of trainees but feedback from some of the large FTOs provided a reasonable estimate of 430 (30%). The forty FTOs were divided into two groups based on annual student training output. A training output of twenty students or more a year provides a good description of an FTO whose primary role is training. Also, to train this number of students in NZ requires a significant amount of instructional and administrative resources. An annual training output of twenty students or more could provide sufficient revenue to justify the cost of acquisition of an FTD or PCATD. In addition, training this number of students by utilising certified FTDs or PCATDs in the curriculum would produce significant cost savings in aircraft usage and fuel. However, small flight schools (under twenty students a year) would struggle to acquire a certified FTD due to their financial constraints but could possibly afford a low cost PCATD. On this basis, an artificial demarcation was made between the large flight training schools (see Fig. 5-1) and the small flight training schools (see Fig.5-2) as determined by student numbers undergoing training in a year.

The majority of small flight schools and aero-clubs in NZ had 5-15 students on their training roster throughout the year and many were training these pilots on a casual or part time basis. These smaller clubs were usually authorised under CAANZ Part 61 rules and fulfilled a number of aviation roles as well as training. They usually provided basic flight training to PPL/CPL standard, as well as support for general aviation recreational flying, and these operations were interspersed with other aviation activities such as flying shows, and competitions. These small flight training schools accounted for approximately 230 students. The survey questionnaire consisted of ten questions and these are outlined in Appendix C. They included questions on the number of students, the deployment of SFTDs, and future intentions concerning the acquisition or SFTDs.

5.3 Results

The forty flight training organisations targeted in the survey were requested to provide actual number of students undergoing training at that specific time. This information is expressed in graphical form in Figure 5-1 and Figure 5-2. The results have to be treated with some caution as flight schools have casual and full time students and attendance can fluctuate. Students, who fail crucial flight tests, lose medical clearances or get into financial difficulties may cease training abruptly. Therefore, for every flight school, pilot trainee completion rates can be difficult to predict. From the results of the survey there would seem to be a large number of flight schools in NZ relative to the population and many of the smaller schools face financial challenges due to the increasing cost of pilot training and small numbers of fee paying students. Five large flight schools (North Shore, CTC, Ardmore, Massey University, Auckland FT, Nelson) account for almost half of the annual total of pilot trainees in NZ.

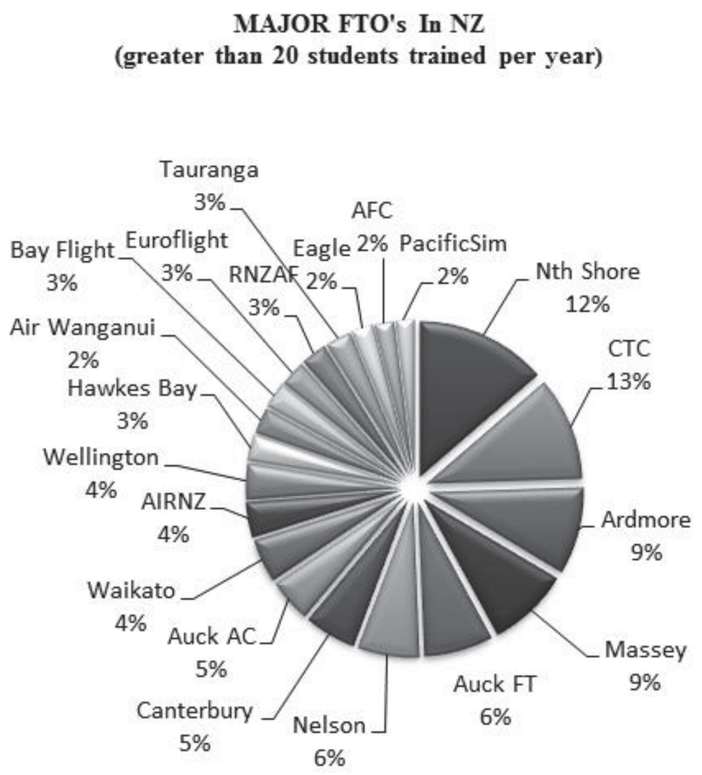

Figure 5-1. Distribution of Trainees in Large FTO's in NZ (Total 1100 Students)

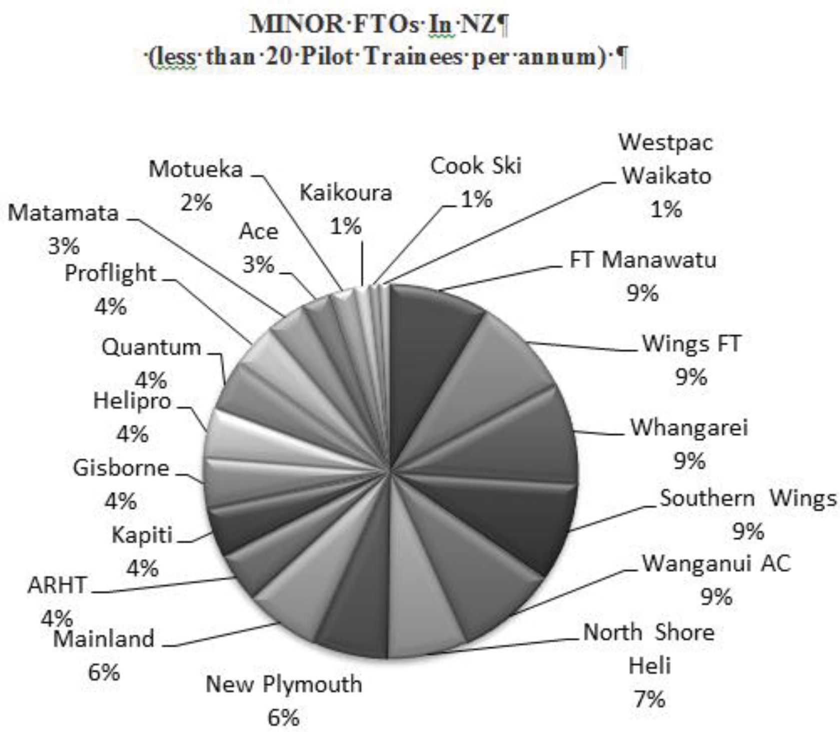

Figure 5-2. Distribution of Trainees in Small FTO's in NZ (Total 230 Trainees)

A number of questions were submitted to the FTOs Chief Flight Instructors concerning their utilisation of FFSs, FTDs, PCATDs, and PTTs.

Q1 Do you currently utilise a CAANZ certified FFS/FTD in your training organisation. If so what type, cost, when purchased?

Only Air New Zealand had the financial resources and the required professional instructors to be able to own and operate a JAR -Level D/ICAO Level II FFS. These flight simulators were utilised to train pilots employed directly by Air NZ. They are also used to train pilots at Mount Cook Airlines, Air Nelson, and Eagle Airways that operate domestic routes on the Air New Zealand Link Network. Air NZ also dry-hires (i.e. hireage without training staff) out these flight simulators to other commercial airlines or flight training schools for airline entry/conversion training (NZTE, 2010). Many of these FFSs cost more than ten million dollars each to purchase and can have operating costs from $400 – $500 an hour (P. Burr, personal communication, 14 May 2012).

Pacific Simulators, based in Christchurch, is the only NZ company that manufactures an advanced FTD (Boeing 737-800 NG) for entertainment and training purposes (Heather, 2009). Currently there is only one of these simulators operating in NZ and is based in Auckland. FLYAJET offers Basic Handling, Jet Handling, and Instrument Rating Courses for Boeing 737 pilot trainees or for those seeking recurrency training. At present, pilot training accounts for approximately 100 hours of simulator time per month. The remaining simulator time is allocated to corporate events and introductory flights (R. Netto, personal communication, 12 July 2012.

Five FTOs were utilising CAANZ certified FTDs at the time of the survey and the most popular model of simulation device was Frasca (see Section 5.1.3.1). These flight-simulation devices are differentiated from PCATDs by certain features such as full replica cockpits that usually represent one aircraft type, fully appointed flight instructor stations, proprietary hardware, and software, hydraulic or servo assisted flight controls, fixed base platforms, and until recently, fairly limited visual displays. In addition, these flight-training devices are distinguished by relatively high levels of CAANZ certification. These training approvals usually include (CAANZ, 2011a):

1 Two hours instrument ground time towards the issue of a Private Pilot Licence;
2. Five hours instrument ground time towards the issue of a Commercial Pilot Licence;
3. Five hours instrument ground time towards the issue of a Category C or B Flight Instructor Rating;
4. Twenty hours instrument ground time towards the issue of an Instrument Rating;
5. Two hours of instrument ground time towards the currency requirements of an Instrument Rating.

Q2. Do you currently utilise a PCATD in your training organisation. If so what type, cost, when purchased?

Thirteen (32.5%) FTOs of the forty surveyed were utilising CAANZ certified PCATDs. Only five flight schools out of the twenty (25%) in the small FTO category had PCATDs. That left eight flight schools out of the twenty (40%) in the large FTO category that did have PCATDs. The NZ FTOs mainly use PCATDs from five different developers:

1. Elite Series – AT-21(superseded by the Elite S612 BITD model), PI 135, IGATE S623 (superseded by the Elite IGATE S712 FNPT 1 model), S623T Helicopter - (Elite, 2012d);
2. Redbird FMZ Motion Simulator - (Redbird, 2012);
3. Aerosoft GA28R – (Aerosoft, 2006);
4. SR3 BK 117 Helicopter (Massey News, 2008);
5. Diamond DA 40 (Glass cockpit) Motion Simulator (CAANZ SOA, 2011).

A common feature of these PCATDs is that they all use MSFS 2002/2004/FSX software to drive the flight simulator. The Elite PACTDs are more flexible in that they provide proprietary Elite software but also allow the use of MSFS in the basic models (Elite, 2012c). This off-the-shelf software flexibility has had a considerable influence on the overall cost of PCATD technology, and has meant developers have been able to construct full motion high fidelity PCATDs for less than $100,000. This was a significant technical achievement as all FTDs currently operating in NZ are fixed base, and usually cost considerably more than that baseline cost (Frasca, 2012b). Another characteristic is that these PCATDs are flexible and can be easily modified to represent different aircraft types. For example, the Redbird motion simulator is versatile enough to be used for single or multi-engine training and can represent glass cockpit aircraft as well as replicate legacy six-pack analog configurations (Redbird, 2010).

Q3. Do you currently utilise a Desktop PC Part Task Trainer in your training organisation (If so what type, cost, when purchased)?

Nine (22.5%) FTO's of the forty surveyed had certified Part Task Trainers. Only one of the small FTO had a certified Part Task Trainer. One hundred per cent of the large FTOs and eighty per cent of the small FTOs reported that their students were using MSFS, X Planes, or Flight Gear software, usually coupled with basic flight controls for part-task training purposes. However, this training was not incorporated into the training syllabus and was being undertaken by students on their own initiative and on an informal basis.

Q4. Do you perceive any immediate benefits in the introduction and utilisation of FTDs, PCATDs, or Part Task Trainers in your respective flight-training programme?

Eleven FTOs (27.5%) of the forty FTOs surveyed, indicated that at the current time they saw no immediate benefit in acquiring an FTD, PCATD, or PTT for training purposes. Surprisingly six of these flight schools were categorised as large FTOs and accounted for training approximately 350 students per year (26% of the total training output).

Q5. Does your FTO intend to purchase or lease any of these devices in the near future?

Eighteen FTO's (8 large FTOs & 10 small FTOs) did not intend to lease or purchase these devices in the near future. Of these eighteen FTOs, four already had FTDs or PCATDs that were fulfilling their training requirements. The remaining FTOs were actively engaged in researching the cost and availability of these devices either for procurement or for upgrading existing flight simulation devices. CFI comments included:

> "The focus is on air time in the cockpit but we are actively looking for a possible purchase of an SFTD in the future."

"The high cost of SFTDs and the low student numbers prohibit any future purchase."

Q6. What are the major factors precluding your use of these devices in your training organisation?

Twelve FTOs indicated that the major factor precluding them from purchasing a commercial FTD, PCATD, or PTT was the high cost of these devices. They were well aware of the high price of commercially available devices and virtually all of them were manufactured overseas, mainly in the USA. Other factors influencing their decision included an unfavourable exchange rate with overseas countries, high cost of importing the device into NZ as well as custom duty and insurance levies. In addition, the high cost of FTD maintenance coupled with the difficulty of finding a local company to support the device. Having to communicate with an overseas company in different time zones when the simulator has technical problems can also be frustrating and time consuming. The FTOs especially those categorised as small were on tight budgets with high overheads when operating their fleet aircraft. They usually did not have sufficient funds to purchase a device despite the fact that there would be long- term economic benefit by reducing hours flown in the air.

A significant factor was the large range of devices that were available commercially. There was much confusion about which synthetic flight training devices were the best to purchase as the market had a bewildering array of models to choose. Some of the FTOs had purchased SFTDs in the past but these were now obsolete. Some of these devices had not worked correctly, even from the initial installation, or had frequently become unserviceable. This had sometimes left a negative impression on flight instructional staff and had been a barrier to future purchases. FTOs had indicated that they desired a reasonable level of standardisation of these devices amongst the different manufacturers to minimise redundancy. The increased pace of technological change meant that even recently purchased SFTD models were quickly being replaced by new models with new technologies. Apart from the PCATDs projects outlined in this thesis and the advanced FTD developed Boeing 737 PCATD by Pacific Simulators, there are no established NZ companies developing PCATD devices. A company developing PCATDs specifically for a local FTO's training requirements could have a significant impact on general aviation training in NZ. Another issue inhibiting the purchase of a PCATD was that many CFIs questioned the fidelity of these devices. For example:

> "My perception is that full motion simulator is required, Fixed Base simulation is not REAL enough. It's OK for procedures but FTD s and PCATDs are too smooth and don't simulate the turbulence of a real flight"

> "High cost & complexity. What you learn in the simulator is not the same as what you learn in the cockpit"

Ten of the twelve FTOs indicated to the researcher that if a PCATD with relatively high fidelity could be produced for $10,000 or less then they would definitely be interested in trialling it.

Q7 *If your training organisation could have access to a NZCAA certified FTD or PCATD at a reasonable cost and it was located less than 100km away would you utilise it?*
Ninety per cent of the FTOs surveyed indicated that they would not utilise a centrally located flight simulator- training centre. Only four flight schools were willing to use a remote facility. The main reasons respondents were against the proposal was the perceived high cost of hiring the equipment, cost of travel, possible accommodation cost, and disruption to the flying programme. There is some evidence of flight training schools using FTDs from other schools or being involved in lease arrangements. For example, Massey Aviation hires the Diamond DA 242 simulator for asymmetric engine training, emergencies, and instrument procedure training. The simulator training is a mandatory requirement for Massey Aviation students who are completing the twin-engine phase of their CPL. The original Frasca 142 and Frasca 242 used by Massey Aviation were sold to another FTO after being decommissioned in 2010 (Massey News, 2007). The Canterbury Aero Club, and International Aviation Academy of NZ, use a centralised Frasca 242 located at their Christchurch training facilities.

Q8. If a customised PCATD were available for your training organisation at a reasonable cost, would your organisation be interested in purchasing such a device?

Twenty-six (72.5%) FTOs (15-large, 11-small) of the forty FTOs surveyed indicated that they would not be interested in purchasing a low cost PCATD. This negative response was probably due to a gradual increase in PCATD ownership by FTOs. On the other hand, many CFIs were familiar with certified FTDs but still had little experience with PCATDs and this may have influenced their responses to those questions.

Q9. Do your students utilise PC-based software such as Microsoft Flight Simulator 2004/FSX or X-planes on an informal basis to assist in their training?

There was a significant affirmative response to this question. Only four FTOs (10%) stated that students were not encouraged to utilise this software at their training school. The primary reason for restricting its use was that the some CFIs believed that unsupervised training in PCATDs might have a detrimental effect on flight training. There was some concern that utilising software in this way may lead to negative transfer of learning. One CFI stated he had students who had demonstrated bad habits in the air from using this software. The students were too fixated on instruments in the cockpit, did not maintain a good lookout, and consequently their airmanship was poor Although recent research on VFR training transfer has not supported this argument (Rogers, et al., 2009).

5.3.1 NZ FTOs with FTDs & PCATDs

Seventeen (43%) of the forty general aviation NZ FTOs identified in the survey incorporated FTDs and/or PCATDs in their flight training programmes. A number of the other flight schools were in the intermediate stages of acquisition of a FTD or PCATD. A few FTOs were upgrading existing devices. The list outlined in Table 5-1 does provide a comprehensive summary of FTOs that utilise flight simulation devices for general aviation training and their current aircraft inventory. Although there is a large range of flight training devices being used in NZ FTOs, the most popular flight simulators are the Frasca FTDs. The US based Frasca company has been well established in NZ for at least twenty years and has been the main provider of certified FTDs for the large FTOs that offer general aviation training (Adams, 2008). However, these devices are expensive and the results of the survey have indicated that Frasca's market dominance is being reduced by the recent introduction of certified PCATDs to NZ. These PCATDs can offer comparable features to conventional FTDS but the difference in cost in most cases is not significant.

Table 5-1. NZ FTOs with FTDs & PCATDs

Flight Training School	**Type**	**Manufacturer-Model**	**Training Aircraft**
Air Hawkes Bay (Part141)	PCATD	Elite AT-21 Microsoft FSX (Informal Use)	Piper Tomahawk - PA 38, Piper Archer / Warrior - PA 28, Cessna 172 - C172, Piper Seneca - PA 34, Piper Super Cub - PA 18, Rockwell Commander 114 - AC 14, Cessna Mustang - C510
Air New Plymouth	PCATD	Elite AT-21	Cessna 152, Cessna 172, P68B Partenavia, PA31 Navajo
Ardmore Flying School	FTD	1.Frasca TruFlite 2. Frasca G1000 Mentor	Piper Tomahawk - PA 38, Piper Archer / Warrior - PA 28, Cessna 172 - C172, Piper Seneca - PA 34, Piper Super Cub - PA 18, Rockwell Commander 114 - AC 14, Cessna Mustang - C510
	PCATD/PTT	Microsoft FSX (Informal Use)	
Auckland Rescue Helicopter Trust	PCATD Developed by researcher	SR3 BK 117 Helicopter	Kawasaki BK 117 Helicopter
Bay Flight Aviation	PCATD	Redbird Motion Simulator	Cessna 152, Cessna 152 (Aerobat), Cessna 172, Piper Seneca, Piper Warrior, Piper Cub , Tecnam P2006T
	PCATD/PTT	Microsoft FSX (Informal Use)	
Canterbury Aero Club (Part141) (IAANZ)	FTD	Frasca 242 (GPS)	Alpha - 160A, Piper Tomahawk - PA38, Piper Cherokee - PA28 140, Piper Warrior - PA28 161, Piper Archer - PA28 181, Piper Arrow, Piper Super Cub- PA18, Robin, Cessna – 172, Partenavia - P68, Piper Seneca
	PCATD/PTT	Microsoft FSX (Informal Use)	
Flight Training School	Type	Manufacturer-Model	Training Aircraft
CTC Wings Hamilton (Part 141)	FTD	Diamond DA 42 KingAir B200	Diamond DA 20 Katana , Diamond DA 42 Twinstar, Piper PA44 Seminole, Cessna172
Eagle Flight Training Ltd	PCATD	Redbird Motion Simulator	Beechcraft Duchess, Cessna 172 Robinson R22 Helicopter, Robinson R44 Helicopter,
Flight Training Manawatu	FTD	AST 300 RussCool King Air C90	Cessna 152, Cessna 172, P68B Partenavia, PA31 Navajo

FTO	Type	Manufacturer-Model	Training Aircraft
HeliPro Aviation Training	PCATD/PTT	Elite AT-21 Microsoft FSX (Informal Use)	Robinson R22 , Robinson R44`, Hughes 500C, Cessna 172
Kapiti Aero Club	PCATD	Elite PI 135	Cessna 152, Cessna 172, Cessna 182. Piper Cherokee , Piper Cub
Mainland Air	PCATD	Aerosoft GA28R	Cessna 152, Cessna 172, Piper Chieftain, Socata Tobago, Piper Seneca III
Massey University, School of Aviation (Part 141)	FTD	1.Frasca 141 2..Frasca 242 3.Frasca TruFlite	Piper Cherokee PA28, Cessna 172, Piper Seneca , Robin) - decommissioned in 2009
	PCATD Developed by researcher	1.SAV1 VFR PCATD 2.SAV2 VFR PCATD 3.Diamond DA40 Motion Simulator	Diamond DA 40 , Diamond DA 42
	PTT	Diamond DA 40 Desktop trainer	
Nelson Aviation College	PCATD/PTT	Elite PI 135	Cessna 152, Cessna 172, Cessna 172 RG Cutlass, Piper Seneca, Robinson R22, Hughes 500C
Royal New Zealand Air Force	FTD	NH 90 Orion Flight Deck Trainer	CT-4E Airtrainer, C130 Hercules, Boeing 757, P3-K Orion. NH90 helicopter, A109UH helicopter, King Air B200
	PCATD Developed by researcher	PTS AirTrainer PCATD	
Southern Wings	PCATD	Elite IGATE S623 (Fixed Wing)	Alpha 160A, Piper Archer PA 28 – 181, Piper Seneca
Waikato Aero Club	PCATD/PTT	Elite AT-21 Microsoft FSX (Informal Use)	Alpha 160A, Cessna 172, Piper Cherokee Archer, Piper Cherokee Arrow, Piper Twin Comanche
Westpac Rescue Helicopter Waikato	PCATD	Elite S623T Helicopter	Bell 222B Helicopter

The PCATDs identified in the survey include the Elite AT-21simulator (Elite, 2010), Redbird FMZ Motion simulator (Redbird, 2010), Elite IGATE S623 Fixed Wing simulator (MFT, 2012), and the Elite S632 Helicopter simulator (Elite, 2012b). In most cases, they can simulate a range of training aircraft and usually include an enclosed cockpit. The flight instrumentation is displayed digitally and there is considerable variation in their out-of-cockpit-view display technologies. Most of the hardware and software systems are proprietary so users are still dependent on the manufacturers for on-going maintenance and support. The Redbird simulator offers new technology for general aviation training in the form of a motion platform, which is electrically driven, moves through 50 degrees of pitch, 60 degrees of yaw and 40 degrees of roll. Nevertheless, all of these devices have some restrictions in terms of fidelity, and customisation for the NZ flight-training environment is limited.

5.3.2 Summary

In the large FTOs (based on student number) the ownership and availability of FTDs, PCATDs, and PTTs was significantly higher (see Fig. 5-3). A number of factors contributed to a lack of ownership in the smaller FTOs. The various responses indicated the reasons for non-ownership were high cost, the lack of government funding, low number of students, complexity, maintenance issues, and a lack of customised hardware and software. Another problem was the wide variety of synthetic flight training devices available on the market and a lack of coordination between FTOs as to which devices would be best suited for their training needs. Some FTOs had purchased equipment that became obsolete, and the cost of upgrading it was prohibitive. According to the survey, the smaller FTOs were slightly more open to the concept of utilising a third party certified FTD for currency training but the main obstacle was lack of suitable facilities (see Fig. 5-4). At present, only one company in NZ provides low cost Boeing 737-800 FTD (fixed-base) currency training to the general aviation sector. This was located in Auckland and could only realistically service pilots from that region. Although the company's main revenue stream is from the entertainment sector it has experienced a modest increase in revenue from its role as a training provider (R. Netto, personal communication, 12 July 2012).

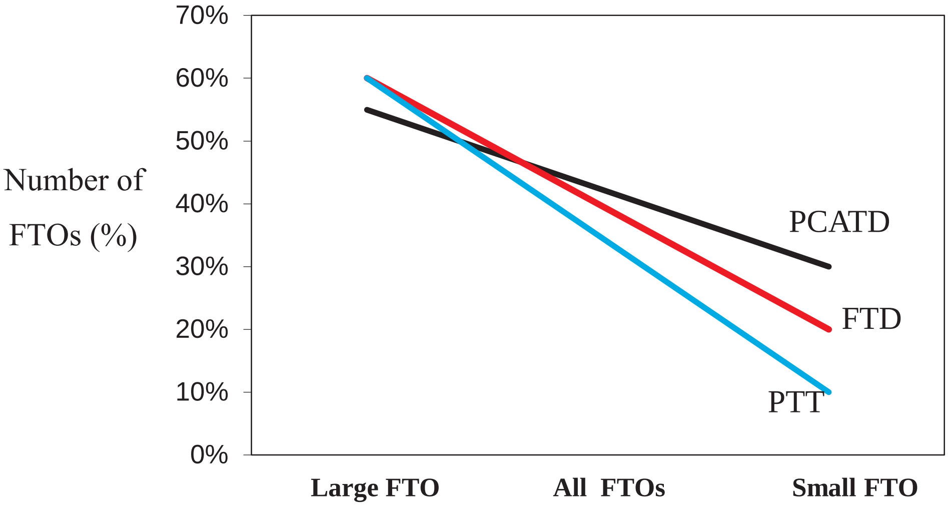

Figure 5-3. Comparison of Ownership of SFTDs between Large FTOs and Small FTOs.

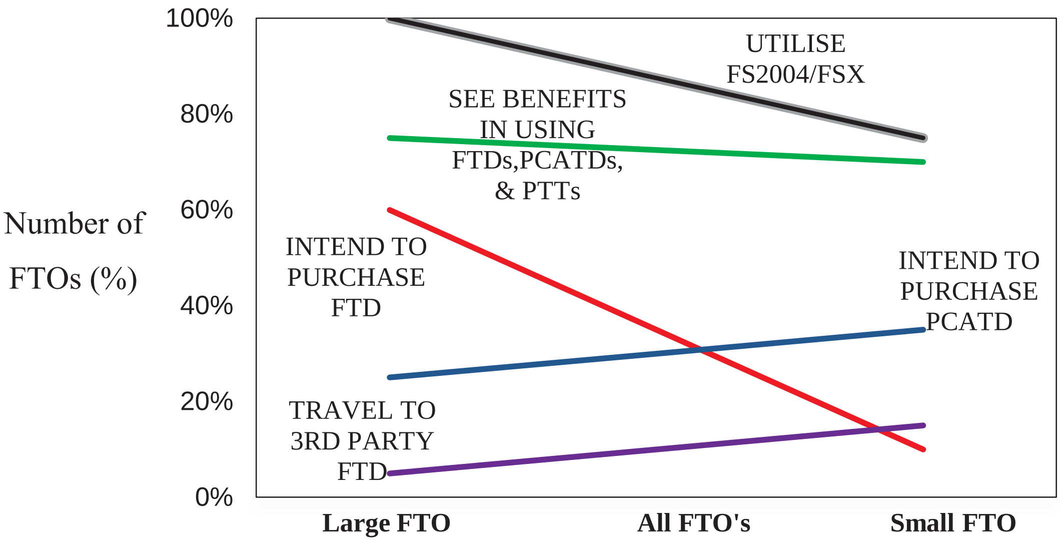

Figure 5-4. Comparison of Survey Responses between Large FTOs vs. Small FTOs

There was little difference between the large and small flight schools in relation to their intentions to purchase a PCATD in the near future and their perceptions of the benefits of using these devices. As expected, most small FTOs were not planning to purchase or lease a FTD at all. Conversely, most large FTOs had definite intentions to purchase a new FTD in the near future. Finally, there was some variation in the use of FS2004 with almost all students in the large FTOs using the software package informally for training purposes and revision. With the lack of flight training devices in the small FTOs, the assumption would be that these students would use FS2004 almost exclusively but this was not the case.

5.3.3 Discussion

With the advent of new technologies especially in the areas of visual displays, flight dynamics, and improved flight controls, PCATDs are becoming more effective as tools for part task training and procedure training. The focus in the past has been on using PCATDs for teaching IFR procedures but new PCATDs models are now offering basic multi-view displays suitable for VFR training (Redbird, 2010). PCATD limitations include low fidelity of the flight controls and cockpit area, and the restricted depth of field in the visual display compared to more sophisticated FTDs (Frasca, 2012b).

Most of the CFI's who responded to the survey had a strong preference for training students in the aircraft. Because of their senior management positions, they had a strong influence on whether or not their particular flying school would acquire a flight-training device by purchase or lease, and the type of device. For example, at the time of the survey one of the largest general aviation flight training schools in NZ did not have an FTD or PCATD in its training inventory.

A key advantage that FTDs have, compared to PCATDs, is that they are more often approved or certified by an NAA (CAANZ, 2011a). Flight schools that own FTDs accrue economic benefits from these IFR/VFR approvals. The cost of operating an FTD is far less than the equivalent cost of operating the aircraft and .with the increasing cost of aviation fuel, the gap is continuing to widen. Nevertheless, the capital outlay to purchase a FTD combined with annual maintenance costs can represent a significant financial investment for the flight school.

The return on investment may take four to five years. Meanwhile the redundancy of the equipment can be rapid especially if the flight school upgrades its fleet or purchases new aircraft types (Massey News, 2009). The flight school would have to have a significant number of students to justify the acquisition of an FTD and currently only one school in the small FTOs category has an FTD. The primary utilisation of these FTDs by the flight training schools was for instrument flight training, especially to assist students to achieve instrument ratings. In most of the FTOs the CFI's regarded FTDs and PCATDs as training aids for procedural training but of limited value in teaching pure flying skills. The purchase of more expensive and more complex certified FTDs by the larger schools was influenced not only by the training advantage of higher fidelity but also by the economic benefit of being able to log IFR currency training hours into student log books. The respective chief flight instructors would encourage instructional staff to ensure that students logged the maximum hours permissible in the FTDs to minimise more expensive aircraft flight time. This meant that very little FTD simulator time is utilised for general training purposes as the majority of the time is allocated for training towards he achievement of instrument ratings.

Consequently very little time in the FTD was assigned for VFR training. Another justification for this was due to some FTDs having very limited visual displays (Frasca, 2006a). The limitations related to either the field of view, depth of field and/or the accuracy of the terrain depiction. The terrain depicted in FTDs usually contains accurate airfield runways and airport buildings but does not display geographic elevation, rivers, or coastline and this makes VFR navigation rehearsal training impractical (Frasca, 2007).Factors such as instructor workload and lack of supervision can inhibit the effective use of these devices. The utilisation of FTDs and PCATDs strictly as instructional aids was very limited in most flying training schools. Flight instructors tend to be saturated with a myriad of tasks that include flying instruction, student briefings, ground instruction, and administration (A. Edwards, personal communication, 12 Dec 2008). The majority of the simulator time was focused on instructor supervision of instrument rating checks and rehearsing instrument approaches.

In addition, many of the CFIs from the smaller flying schools were less convinced that PCATDs could assist their training programme especially with VFR procedures training. The flight instructors' criticism of PCATDs was mainly centred on the lack of fidelity and limited visual displays of the devices they had previously encountered. Despite the large volume of research that indicated a high degree of transfer of learning from PCATD to aircraft (Leland, et al., 2009; Taylor, et al., 2004), they seemed reluctant to use these devices to assist with flying training. The survey results did indicate that virtually all of the flying training students were pooling their own resources and setting up customised PCATDs (consisting of a computer, basic controls, and flight simulation software) in their respective pilot lounges, operations area, or at home. These ad hoc devices were not incorporated into the formal training programme but were used on an informal basis by the students. In addition, many students were developing their own scenarios with customised aircraft and scenery. There was only one instance where a student's PCATD was physically removed from the operations room by a CFI because he was worried that the device might be encouraging bad habits in the actual operation of the aircraft. The main issue with the informal use of such devices is that flight instructors have no control over what software is being input into these devices and how they are being utilised for training.

This suggests that flight instructors would be supportive if students could use a PCATD in unsupervised sessions as well as a database of programmed learning IFR & VFR scenarios. Ideally, the software modules would also generate a numerical score or create a visual record of the flight, which a flight instructor could evaluate at a later stage. To be effective, the utilisation of PCATDs must be balanced with the use of other resources within an FTO's training programmes. They are multipurpose tools and rather than being used only as flight simulators in direct competition with FTDs, they could be used effectively in other areas such as a classroom teaching aid for mass briefs, in resource management exercises, and for remedial training (Alessandro, 2008). Many smaller flying training organisations in NZ could enhance their training programmes by using PCATDs. Survey results indicate that it is unlikely that the majority of FTOs will have the financial resources to justify the purchase of an expensive FTD. In addition, it is clear that in the majority of flying schools in NZ the utilisation of PCATDs is already taking place albeit in a much unstructured way by the students themselves.

The increasing demand for glass cockpit training on general aviation aircraft could also be satisfied with the development of a standardised PCATD that incorporates a comprehensive package of scenario based learning modules.. A number of studies have demonstrated that PCATDs can be used effectively for VFR exercises that could include ab-initio training, circuits, navigation, and upset recovery training (Bone & Lintern, 1999; Rogers, et al., 2009; Vaden, Westerlund, Koonce, & Lewandowski, 1998). This developing technology has the potential to be a useful training aid for all FTOs especially in the area of VFR flight procedures that accounts for most of the general aviation flight-training hours in NZ. Overall, the results of the survey support a requirement for further research into the development of a relatively inexpensive, customised PCATD that displays high-resolution terrain coupled with a comprehensive airport database that could be used for flight training by NZ based FTOs.

Chapter 6. PCATD Projects

Five PCATD projects are outlined in this chapter. They include:

1. Stage 1: Development of Royal New Zealand Air Force Pilot Training Squadron IFR/VFR PCATD;
2. Stage 2: Development of a PCATD for Helicopter IFR/VFR Training;
3. Stage 3: Development of the SAV1 PCATD for Visual Flight Rules Procedural Training;
4. Stage 4: Development of the SAV2 PCATD for VFR Training & Comparative Study;
5. Stage 5: Development of Massey School of Aviation Diamond DA 40 IFR/VFR PCATD.

Each stage includes a brief but focused literature review that outlines studies that are closely related to the particular PCATD development project. A description of the development phases of the PCATD is followed by a detailed evaluation of the device. Each stage then concludes with results and a discussion.

6.1 Stage 1: Development of the RNZAF Pilot Training Squadron PCATD

6.1.1 Introduction

There was some concern in the RNZAF Pilot Training Squadron (PTS) that after the introduction of the new Airtrainer aircraft, a number of students might have difficulty with the internal Instrument Rating Test (IRT) (A. Butt, personal communication, July 13, 2009). PTS did not have any flight simulation devices in its inventory and at the time there were severe budgetary constraints imposed by the Ministry of Defence. A feasibility study was implemented to investigate the development of three low cost desktop PC IFR/VFR procedure trainers for the RNZAF trainee pilot programme (RNZAF, 2012). A modest financial allocation was approved for the project but after some investigation, it was found that most commercially available FTDs exceeded the approved budget. The decision was made to develop a PCATD prototype using a combination of low-cost commercial of-the-shelf (COTS) hardware and software, and interface systems developed with RNZAF internal resources. Military pilot training does differ from general aviation flight training, as there is a strong emphasis on achieving a high level of VFR skills. Military flight training involves a significant amount of training devoted to mastering formation flying, low flying, and aerobatics (PTS, 2004). This type of skill training is much less common in civilian flight training schools. With less time to consolidate (IFR) procedures, some pilot trainees could struggle with the demands of advanced VFR flying and learning complex instrument approaches. It was hoped that the use of PCATDs for instrument procedures rehearsal, would assist with the final Instrument Rating Assessment. A secondary aim of the project was to use the PCATD for basic VFR procedural training such as practising emergencies procedures, climbing and descending, straight & level, stalling, and procedural turns.

6.1.2 Background

The RNZAF's Pilot Training Squadron (PTS) operates from RNZAF Base Ohakea located near the city of Palmerston North. Training at PTS comprises classroom work and flying instruction on the CT-4 Airtrainer (RNZAF, 2012). The CT-4 is a dual seat, single engine, and low wing, all-metal monoplane with fixed tricycle undercarriage that is able to operate in VFR and IFR conditions (see Fig.6-1). In August 1998, the RNZAF received the first upgrade of thirteen-leased CT-4Es. Pilot Training School and Central Flying School (trains flight instructors) fly only CT-4E Airtrainers, and the combined annual flying hours allocated to these units is 6,800 (RNZAF, 2012).

Pilot training in the RNZAF is intensive and complex and can include university cadetships. Although unverified, it is estimated that when the entire infrastructure is taken into account, it costs almost a million dollars to train an RNZAF pilot to operational readiness. Military ethos requires pilots to be operationally prepared for rapid deployment to overseas theatres where conflict may be occurring. The demands of operational flying are reflected in the training course structure. The elements of flight training are as follows:

1. RNZAF Base Ohakea, Manawatu - Wings Training Course

   Pilot trainees commence their Wings Course training, at Pilot Training Squadron (PTS). Initially the trainees complete five weeks of ground school, where they are taught subjects such as principles of flight, airmanship, and technical specifics of the 300HP CT-4E Airtrainer aircraft. Flying training lasts for approximately nine months and the trainees accumulate approximately 130 hours in flying the Airtrainer, covering navigation, aerobatics, instrument flying, formation, low flying, remote airfield operations, and night flying.

2. No 42 Squadron – Advanced Flight Training

For five months students are posted to No 42 Squadron, receive further training (90 hours) on the twin engine King Air aircraft, and are assessed as single pilot captains. On completion of the King Air phase, successful graduates receive the coveted Pilots Brevet (Wings) and continue their career as an operational pilot in the RNZAF (Air Force News, 2010).

Figure 6-1. RNZAF CT4-E Airtrainer

Source: (Heap, 2005) - RNZAF CT4/E Airtrainer. Retrieved from http://www.airliners.net/photo/New-Zealand--/Pacific-Aerospace-CT-4E/0759079/&sid=d5b90a156de3c94d857b4042f375d5e9

6.1.3 Literature Review

Recent technological advances in the capabilities of personal computers have resulted in an increase in commercially available PCATDs. These devices are generally low cost with moderate fidelity, compared to FTDs and FFSs that more closely resemble the physical characteristics of a real aircraft. PCATDs are different to formal flight training devices such as FTDs in that they are integrated, ground-based training devices that are used solely for aviation training purposes, and generally not for pilot qualification or civil aviation certification. William's (2001a) research found that increased use of PCATDs by flight training schools and individual pilot trainees could assist with the delivery of flight training instruction and enhance flight safety. This was particularly relevant to the RNZAF pilot training system as it has its own internal certification process. RNZAF pilots can voluntarily undergo external examinations such as commercial pilot licences (CPL) or air-transport pilot licences (ATPL) but they are not required to fly military aircraft. Civilian trained pilots prefer to train on certified simulators as this provides an economic and training advantage. By using FTDs, they can reduce the more expensive IFR aircraft hours they require for an instrument rating.

The FAA (1997) initially released guidelines, which outlined the specific number of hours that an approved PCATD could be used in lieu of aircraft hours (e.g. 10 hours towards a PPL–Part 61). What the Pilot Training Squadron was more interested in was the suggestions in the FAA qualification guidelines on what PCATD design should be, and how they could be used effectively. The FAA's recommendations for the design and use of PCATDs included the establishment of an integrated and flight training programme that:

1. Contained modules/elements of ground and flight training;
2. Combined knowledge based skills with psychomotor skills for each flight task;
3. Consolidated classroom knowledge with procedure rehearsal (PCATD use) and then psychomotor skill rehearsal (FTD, FFS, or aircraft).

Despite the great potential of PCATD training, a cautionary note was sounded by the Training Systems Division of Flight Safety International, the world's largest training organisation for professional pilots. The company uses MSFS extensively to enhance the ground school experience. Nevertheless, the Manager emphasised, that micro simulation software and hardware could not replace high fidelity flight simulators used by airlines and the military. "You cannot replicate that in a PC environment," (BaseOps.Net, 2007, p.1).

6.1.4 Development of RNZAF PTS IFR/VFR PCATD.

One major project challenge was that only a limited budget allocation (excluding labour costs) was available for developing three PCATDs, well below the cost of purchasing a commercially available FTD. The three PCATDs were designated as PC-based IFR/VFR Rules Procedural Trainers and training documentation was produced. The FS2004 software release produced increased frame-rate performance and improved visual effects `such as haze/visibility, texture filtering, and virtual cockpit views (i.e. a cockpit view that provides 3D cockpit panning (Baker, 2003).

A substantial expansion of the scenery database was included in the release of FS2004. Although there was a significant increase in available airports for take-offs and landings, planning flights in between them was impossible without using third-party software tools. The database of navigational aids was simply a text listing of navigational transmitters and beacons, and detailed area maps were provided only for the forty-five major cities in the world. Even though this was an improvement upon the previous version of MSFS, which had no maps at all, it was still a major limitation.

Other technical innovations that were examined included Force Feedback joysticks. These joysticks could simulate turbulence, bumpy runways, and stick shake that indicates incipient stall conditions .(Deemer, 1997). Although they were trialled for this project they were not considered realistic enough for flight training by the flight instructors and were eventually replaced with standard joysticks.

6.1.5 Initial PCATD Evaluation

The original PCATDs were designed to include the following components (see Fig. 6-2):

1. Compaq PC with 3D Graphics Card;
2. Single 19“ CRT Monitor;
3. Microsoft compatible Saitek Joystick and Throttle Quadrant (Rudders were simulated on the Joystick with a lateral twist motion);
4. Microsoft Flight 2004 with customised scenery and aircraft flight models;
5. Utility programs such as FS Flight Recorder.

Figure 6-2. PTS IFR/VFR PCATDs

This fairly simple PC-based structure was similar to other desktop based PCATDs that had been developed around the world (Williams, 2006). However, it required significant in-house software development to simulate the Airtrainer aircraft correctly. The aircraft was unique, with a powerful engine and flying characteristics quite dissimilar to other general aviation aircraft. Therefore, it was necessary to follow the action research methodological approach. The steps included developing a prototype, obtaining feedback from flight instructors, and then implementing the incremental improvements required to obtain an accurate flight model and increase the training effectiveness of the device. An initial evaluation of the first working prototype was undertaken and focused mainly on technological issues:

1. The MSFS default Cessna Flight model was not accurate or specific enough to be modified as a generic model for the RNZAF CT-4E aircraft. The glide ratio, climb, and descent rate of the Airtrainer was markedly different from the default Microsoft aircraft. A specific flight model had to be created.
2. Force feedback joysticks were trialled but the sensory output was determined to be too erratic and inaccurate. Therefore, standard joysticks were used instead.

3. The default MSFS terrain was 1200 metres resolution (Level of Detail 5). All major NZ airports were present in the default terrain but consisted of a single runway or runways with a few randomly placed generic buildings. This level of scenery and terrain detail was initially determined to be adequate but a later evaluation by flight instructors contradicted this.
4. When practicing IFR procedures, a significant aspect of flying instrument approaches is re-orientation after breaking through overcast clouds to minimum authorised heights. Therefore, the correct level of terrain detail was critical. In this particular case, the default NZ terrain did not have sufficient resolution for trainee pilots to determine if they were on the correct runway approach, or actual runway.
6. Joystick control was highly sensitive, and over-controlling was an issue when trainees were flying instrument flight approaches.
7. Digital gauges on the instrument panel were low resolution and were difficult to read in real time. Some custom gauges were not simulated due to their complexity.
8. Some local area Navaids (e.g. NDB, VOR, and VORTAC) either were set at an incorrect frequency or were non-existent.

The development of a CT-4E flight model was a major programming challenge as the aircraft is a unique, highly manoeuvrable, aerobatic aircraft with small wings, and a poor glide ratio. Despite these challenges, an accurate flight model for the CT-4E was developed, which was subsequently approved by the Commanding Officer PTS for simulation training. Specific local scenery was also created such as the RNZAF Ohakea airfield and surrounding training areas (see Fig. 6-3).

A number of software and hardware upgrades of the PCATDs were undertaken as an integral part of the feedback-improvement loop of the action research cycle. These improvements are outlined in Table 6-1. These improvements included upgraded visual graphic capability, larger LCD monitors, and the installation of the latest version of MSFS. A number of new software packages (e.g., NZ local terrain, & Ohakea Airfield) were also fully incorporated into the PCATD. These include more customised panel design models and accurate visual and flight models.

Figure 6-3. CT-4E Airtrainer. – RNZAF Base Ohakea Custom Aircraft & Scenery

Table 6-1. PCATD Continuous Improvement Cycle (Action Research)

Version	Software Upgrade	Hardware Upgrade
Prototype	1. Local Scenery Developed 2. CT-4E Flight Model 3. Update Navaids 4. Update Gauges 5. Joystick Sensitivity Controller	1.Upgrade to 19” Monitor
Operational Version – FS2004	1. Local Scenery Upgrade 2. Custom gauges developed	1. Joystick Stands
Operational Version – FS2004	1. Update Navaids 3. Update Gauges	1. Upgrade PC (multi-core) 2. Upgrade Graphics capability 3. Upgrade LCD Monitor
Operational Version – FSX	1. Upgrade to FSX 2. Update Navaids 2. Update Gauges	

One major advantage of Microsoft Flight Simulator’s open software architecture was the emergence of new specialised software packages that could be used in the PCATD. This ensured that the PCATD did not incur on-going development costs as relatively inexpensive COTS software became more readily available (Frat Bros Design, 2010). The next step was to undertake a technical evaluation of the new hardware and software followed by a training evaluation by a small focus group of flight instructors.

6.1.6 Preliminary Evaluation of the RNZAF PCATD Prototype

The evaluation of the PCATD was driven by three primary objectives. Could the PCATD be used effectively for:

1. Basic & Advanced IFR task training?
2. Basic VFR task training?
3. Emergencies training?

6.1.6.1 Preliminary Evaluation of Prototype

Once the initial prototype was built, five questions were presented to a focus group of three senior flight instructors to determine if the PCATDs had sufficient fidelity and capability for RNZAF IFR/VFR training. At the conclusion of this basic evaluation of the RNZAF PCATD prototype, a roundtable discussion was held and feedback was provided.

The five questions presented to the flight instructors were as follows:

1. Is the physical fidelity of the flight controls of the RNZAF PCATD at a high enough level in terms of accuracy and feedback response to conduct effective IFR/VFR training?

The flight instructors indicated that flight controls were adequate for IFR/VFR training but expressed reservations about flight control sensitivity. Software modifications to joystick axes were made to reduce sensitivity in the elevator and rudder axes. Maintaining altitude and attitude control was much more difficult than the aircraft. However, the flight instructors felt that this might be an advantage in training transfer, as the pilot trainee will improve their fine motor skills. It was agreed that flying control fidelity would be a limitation in training in the PCATD but that future technologies may solve this issue.

2. Is the resolution of NZ terrain & runways depicted in the RNZAF PCATD accurate enough to conduct effective IFR/VFR training?

In the professional opinion of the flight instructors, the default scenery mesh at 1200-metre resolution was high enough to accurately display the airfield and surrounding terrain. Therefore, the terrain was upgraded with 150-metre resolution mesh (Stock, 2006). The flight instructors found this new resolution to be suitable for IFR/VFR task training.

3. Does the flight model characteristics of the CT-4E Airtrainer model depicted in the RNZAF PCATD accurately match the real aircraft?

There was considerable debate about the revised flight model of the Air Trainer CT-4E. The aircraft has a powerful 300 HP engine, with a strong airframe and is fully aerobatic. However, it has short wings with a relatively low aspect ratio and therefore has relatively poor glide characteristics. A number of flight models with differing characteristics were developed and the flight instructors took some time to come to a consensus on the most accurate flight model. For example, increasing the power and drag coefficient improved overall performance but created unexpected effects in other areas, such as an unrealistic rate of climb. Eventually a compromise was made and the most adaptable flight model was trialed and installed into the PCATD.

4. Is the instrument panel depicted in the RNZF PCATD realistic enough to conduct effective IFR/VFR training?

Basic flight instruments had high-resolution dials inserted into them to improve readability. A number of custom gauges peculiar to the Airtrainer (for example, Manifold Pressure, Fuel Flow) had to be coded in-house. The flight instructors indicated that the digital instrument panel was a superior feature of the PCATD.

5. Do the RNZAF PCATDs out of cockpit views provide FOV fidelity at a high enough level, to conduct effective IFR/VFR training?

MSFS can simulate different outside cockpit views. For training purposes, the flight instructors determined that either the virtual cockpit view or panel view set at 0.75 magnification was the most realistic outside cockpit view for the PCATD. The visual display had a field of view of only ninety degrees, which limited its usefulness for advanced VFR skills training but was sufficient for basic VFR manoeuvres such as straight & level, descending and climbing, and procedural turns. Depending on whether faults identified in the evaluation could be rectified and whether certain improvements were feasible, a request was made by the developer to introduce the PCATD (supported by a suitable training programme) into the curriculum. No statistical analysis was undertaken on this preliminary evaluation. Nevertheless, after some deliberation, the flight instructors agreed to proceed with the installation of the PCATD into the flight-training programme.

6.1.7 Introduction into Training Curriculum

Although the RNZAF PCATD had limited flight control fidelity and visual fidelity compared to a certified FTD, the flight instructor focus group expressed confidence in the training potential of the device. A major advantage of the technology was its low cost ($5000) and modular construction. The flight instructors were also made aware that new technologies were continually emerging and current limitations in fidelity could be resolved in the future. The PCATD was fully incorporated into the IFR/VFR training syllabus for Pilot Training Squadron and is still currently being used to train student pilots (N. Pedley, personal communication, July 13, 2012). Six simulated instrument training sorties are now included in the PTS flying training syllabus (see Table 6-2). Each simulation sortie takes approximately 45-60 minutes to complete and includes briefing and debriefing by the flight instructor. Some of the sorties (without external visual reference until the aircraft is on final landing approach) include the following in instrument flight procedures:

1. Instrument Flight Scan - Scanning of primary instruments;
2. DME Arc - Flight Tracking along an Arc using Distance Measuring Equipment;
3. SID – Standard Instrument Flight Departure;
4. VOR[8] – VHF Omnidirectional Range;
5. VORTAC - VHF Omnidirectional Range/Tactical Aircraft Control;
6. NDB Hold – Non-Directional Beacon Hold Patterns.

[8] VHF omnidirectional radio range (VOR), is a short-range radio navigation system that enables aircraft to fix their position and follow a magnetic heading by receiving radio signals transmitted by a network of fixed ground radio beacons (Kayton & Fried, 1997).

These instrument flight rules procedure exercises are a good representation of the standard type of instrument approach commonly practiced by pilots at the equivalent CPL and ATPL level. Some VFR manoeuvres were also practiced in conjunction with IFR training such as visual runway approaches, landings, and take-offs.

Table 6-2. PTS Simulator Instrument Flight Rules Training Sorties

NO.	SORTIE	AIRCRAFT POSITION	ALT	HDG	CLOUD	WIND	AIM
SIM 1	IF 1-2	OH 300r @ 10NM	5000’	300NM	Nil	Nil	IF Scan / S + L / Turns / Climb / Descent
SIM 2	IF 3	OH 300r @ 10NM	5000’	300M	Nil	270/20 knots	Tracking / Arcing
SIM 3	IF 4-6	Threshold RWY 27	164’	270 M	Nil	270 / 20 knots	IFTO / SID / FLWOP (IMC)
SIM 4	IF 7	OH 060 R @ 1NM	4000’	0670 M	Nil	Nil	VOR Hold
SIM 5	IF 9	Overhead WU	3000’	115M	BKN 3500’	090 /15 knots	VORTAC 15 (via arc) & MAP
SIM 6	IF 7 & 10	10 NM South-East WU	3000’	315M	BKN 3500’	110 /10 knots	NDB Hold & App WU & MAP

Source: **(**PTS, 2004, p.30)**-** PCATD Training Manual PTS:

6.1.8 Evaluation of RNZAF PCATD by Pilot Trainees

An evaluation was undertaken by purposively selecting RNZAF pilot trainees who were currently undergoing military pilot training at PTS.

6.1.8.1 Participants

For security reasons, information on aircrew trainees was limited. From 2000-2006 the RNZAF Pilot Training Squadrons trained to graduation approximately 5-10 ab-initio students per year. However, demographic information was not obtainable for these trainees for that period. During the period 2007-2012, the total number of graduates was thirty-four and the median number of graduates was five per year. RNZAF selection criteria stipulate that all aircrew trainees must be at least 17 years old and be physically fit.

The demographic composition of these pilot trainees (2007-2012) was as follows:

1. Two pilot trainees were female;
2. Three were regular Naval Officers;
3. All pilot trainees ages ranged from 17-27;
4. Four trainees had previously served in the NZ armed forces in a ground role;
5. Three were positively identified as university graduates (one from the RNZAF University scheme);
6. Three were identified as recent high school leavers.

The average age of the trainees was 23 and they represented 17% of the total number of trainees who had competed training during the period 2007-2012. A summary of the trainee's flight experience is listed in Table 6-3. In the last few years, most RNZAF pilot courses have been reduced in size and a maximum of 5-10 pilot trainees are usually selected per course.

Table 6-3. Aircraft & PCATD Training Experience

Pilot Number	Total Flight Time Aircraft –Hrs.	Total IFR Time Aircraft-Hrs.	Total PCATD - Hrs.
1	120	10	10
2	120	10	10
3	125	13	20
4	125	10	30
5	130	10	10
6	155	14.9	7
7	120	15	20
Median	125	10	10

6.1.8.2 PCATD IFR/VFR Survey by RNZAF Pilot Trainees

The purpose of this survey was to use current trainee pilots to complete a flight task procedure and an evaluation of the fidelity and usability of the PCATD (see Appendix E). They had to provide ratings of its task effectiveness and level of fidelity. Only seven pilots were available to complete the evaluation because they were the only users of the RNZAF PCATD at the time of the survey, and were nearing the completion of their pilot training. The evaluation took place over a one-month period. The students completed the requirements outlined in the evaluation form and this process was co-ordinated by a senior flight instructor at PTS. The survey data was recorded and analysed to provide an overall evaluation of the RNZAF PCATDs, and their effectiveness in IFR/VFR training.

6.1.8.3 Cognitive Walkthrough

The RNZAF pilot trainees were required to complete a cognitive walkthrough[9] by practicing eleven different IFR/VFR tasks in the PCATD in any sequence. The tasks had been chosen for the following reasons:

1. Close similarity to the tasks outlined in the McDermott (2005) study to have a point of comparison. In fact nine tasks were identical;
2. Consultation with flight instructors at PTS to establish which training tasks were the most relevant to the PCATDs use in the syllabus of training ;
3. The tasks were also relevant to Stages 2-5. This was necessary for continuity, and as a comparative measure between ratings of similar flight training tasks in different PCATD projects.

The IFR/VFR tasks were:

1. Instrument Scan (IFR/VFR). This task involves visually scanning the instrument panel in a set pattern;
2. Airspeed Control (IFR/VFR). This task involves setting and maintaining correct airspeeds;

[9] The cognitive walkthrough method is a usability inspection method used to identify usability issues in a piece of software/hardware , focusing on how easy or hard it is for new users to accomplish tasks with the system (Dix, Finlay, Abowd, & Beale, 2004)

3. Altitude Control (IFR/VFR). This task involves setting and maintaining correct altitude;
4. Navaid Tracking (IFR/VFR)-Adv. This task involves tracking the aircraft to a navigation beacon or reporting point.
5. Procedure Turns (IFR/VFR). This task involves completing timed procedure turns;
6. Holding Patterns (IFR/VFR). This task involves entering into timed holding patterns and orbiting as at a designated altitude;
7. Intercept Localiser (IFR). This task involves intercepting a navigation beacon and tracking to or from the beacon;
8. Intercept Glide Slope (IFR). This task involves-intercepting and following an Instrument Landing System glideslope;
9. Missed Approach (IFR). This task involves initiating a missed approach procedure after descending to a decision height on final approach and not visually seeing the runway;
10. SID[10] Rehearsal (IFR). This task involves rehearsing a Standard Instrument Departure procedure;
11. STAR[11] Rehearsal (IFR). This task involves rehearsing a Standard Terminal Arrival Instrument procedure.

In the first phase the pilot trainee practiced a procedure or training task (e.g., Missed Approach) that could be completed as a component of a complete training procedure (e.g., full instrument approach) or as a completely separate, individual exercise (Forrest, 2000). Each procedure took approximately thirty minutes to complete but they were able to repeat the procedure until they felt confident that they had mastered it. The trainees then practiced eleven IFR procedural tasks listed on the evaluation sheet, in the PCATD.

[10] Standard instrument departure (SID) routes are published flight procedures followed by aircraft on an IFR flight plan immediately after take-off from an airport(USAF, 2005)

[11] A standard terminal arrival (STAR) is a published procedure followed by aircraft on an IFR flight plan just before reaching a destination airport(USAF, 2005)

There was no specific time limit but they could practice the IFR/VFR procedure until they completed it successfully. Some procedures can take some time to evaluate so all of the pilots had logged at least ten hours of evaluation time on the PCATD. This was sufficient time to practice and evaluate the various IFR/VFR tasks either in combination or individually. At the end of each of the eleven assessments of the IFR/VFR tasks, the pilots had to rate the following statement using a Likert scale:

Practicing this particular IFR/VFR flight procedure or manoeuver in the PCATD can improve proficiency in the aircraft.

A Likert scale was used that provided a range of responses that measured the respondent's intensity of feeling concerning the statement. A decision was made to make it a five point scale which was similar to the ratings used in previous studies (Johnson & Stewart II, 2005; Stewart, 2001). The response/evaluation categories were *Strongly Disagree* - rated 0, *Moderately Disagree* - rated 1, *Neutral* – rated 2, *Moderately Agree* - rated 3, *Strongly Agree* - rated 4. One non-scoring category was included, *Unable to Rate* - where the evaluator had not reached a sufficient level of expertise to rate the task or was unavailable.

6.1.8.4 Heuristic Evaluation

A heuristic[12] evaluation, is a usability inspection method for computer software and hardware that helps to identify usability problems in the user interface (UI) design of a training device (Forrest, 2000). This methodology can provide quick feedback to the designer and feedback can be obtained quite early in the design process. Heuristic evaluations usually are conducted by a small set of evaluators. The evaluators independently examine a user interface and judge its compliance with a set of usability principles (Usability.gov, 2012).

[12] Heuristic evaluation is conducted to provide feedback to the developers on the extent to which the interface is likely to be compatible with the intended users' needs and preferences (Nielsen & Molich, 1990

A heuristic evaluation was undertaken in a study by Forrest (2000) which examined expert evaluations of a PCATD. This study used seven evaluation statements. These included statements like "Response of the PCATD to user control input is adequate for primary instrument training" and "The overall simulation of the PCATD is adequate in terms of realism as applied to primary instrument training" (p.30). Ordinal responses measured the level of agreement to each statement. A rank of (1) represented complete agreement and (9) complete disagreement. The highest mean ranking was 2.3 and the lowest mean ranking was 1.3, which indicated the scale might have been too long as all ranked responses were less than 5. The least level of agreement from any one particular response was 4. The mean rank of all questions was 1.8. There were some limitations in Forrest's (2000) study. For example, there were only three evaluators, and a non-standard Kruskal-Wallis ANOVA test was performed to measure the level of agreement between instructors and their evaluations. In addition, taking into consideration the scale adopted in Forrest's study and the limited range of ranked responses, a decision was made to adopt a five point ordinal scale for the heuristic evaluation of the RNZAF PCATD.

A heuristic evaluation was then implemented for the RNZAF PCATD and the pilot trainees had to evaluate six statements that related to the user interface and level of fidelity of the PCATD. The content of these evaluation statements were based on related questions generated in the preliminary evaluation of the RNZAF PCATD prototype, and in Forrest's (2000) study. The statements (except for statement 6) were closed and could only be evaluated with one of the five Likert responses (e.g., *Strongly Disagree, Moderately Disagree, Neutral, Moderately Agree, and Strongly Agree*):

1. The physical fidelity of the flight controls is at a high enough level in terms of accuracy and feedback response to conduct effective IFR/VFR training;
2. The resolution of the NZ terrain depicted in the PCATD is accurate enough to conduct effective IFR/VFR training;
3. The flight model characteristics of the Airtrainer CT4E developed for the RNZAF PCATD accurately match the real aircraft;

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to conduct effective IFR/VFR training;
5. The instrument panel depicted in the PCATD was realistic enough to conduct effective IFR/VFR training;
6. What other issues concerning the PCATD did you notice while performing the evaluation (Problems, concerns, improvements, limitations, etc.)?

6.1.8.5 Inter-Rater Reliability

Krippendorff's alpha coefficient was used to measure inter-rater reliability and level of agreement. The coefficient is a statistical measure of the agreement achieved when coding a set of units of analysis in terms of the values of a particular variable (Krippendorff, 2008). It is used as a measure or measures of inter-coder agreement, inter-rater reliability, and reliability of coding. Unlike Fleiss Kappa, (which has to have an equal number of raters per category) Krippendorff's alpha can be applied to any number of evaluators, each assigning one value to one unit of analysis, to incomplete (missing) data, to any number of values available for coding a variable, to binary, nominal, ordinal, interval, and ratio metrics, and it also adjusts itself to small sample sizes of the reliability data.

The advantage of a single coefficient with these variations is that computed reliabilities are comparable across any numbers of evaluators and values, different metrics, and *unequal sample sizes* (Krippendorff, 2008). To avoid the risk of drawing false conclusions from unreliable data, it is common to relate a high level of reliability and agreement when $\alpha \geq .800$, and a medium level of reliability and agreement to data with $0.800 > \alpha \geq 0.667$, and a low level of reliability and agreement when $\alpha < 0.667$ (Krippendorff, 2004).

6.1.9 Results

The results are presented in three parts. First, the results from the practical evaluations of the PCATD in relation to the IFR/VFR tasks are listed. Then descriptive statistics (Mean & Standard Deviation) were used to measure the eleven task results. Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha can cope with incomplete data, and adjusts for small sample sizes (Krippendorff, 2004). Then six heuristic evaluations of fidelity of the PCATD and user interface are described qualitatively, with comments made by the RNZAF pilot trainees.

6.1.9.1 RNZAF PCATD Task Evaluation

The eleven tasks combine IFR and VFR procedures. There were three basic tasks, and eight advanced tasks that were evaluated and their results are listed in Table 6-4. Overall, the results indicated that the pilots' task analysis of the effectiveness of the PCATD produced a positive evaluation (above Neutral) for eight of the IFR/VFR tasks. Only one trainee felt that there was no improvement in instrument scan, intercept localiser, and intercept glide slope. Four of the seven trainees indicated that there was no improvement in airspeed control and altitude control, which indicated that there were still some difficulties with flight control fidelity.

Table 6-4. Trainee Pilot Ratings for Practical Evaluation of IFR VFR Tasks

IFR/VFR Flight Tasks (Basic & Advanced)	No. of Participants	Mean (0-4)	Standard Deviation
Instrument Scan (IFR/VFR)-Basic	7	2.4	0.98
Airspeed Control (IFR/VFR-Basic	7	1.1	0.89
Altitude Control (IFR/VFR)-Basic	7	1.4	0.98
Navaid Tracking(IFR/VFR)-Adv	7	3.4	0.53
Procedure Turns (IFR/VFR) –Adv	7	3.0	1.4
Holding Patterns(IFR/VFR)-Adv	7	3.3	0.49
Intercept Localiser(IFR)-Adv	6	2.3	1.4
Intercept Glide Slope(IFR)-Adv	5	2.4	1.5
Missed Approach(IFR)-Adv	7	2.7	0.29
SID Rehearsal(IFR)-Adv	7	2.9	0.38
STAR Rehearsal (IFR)-Adv	4	3.0	0.00

Most of the trainees indicated that using the PCATD improved their Navaid tracking, procedural turns, holding patterns, missed approach, and standard instrument departure (SID) procedures. Four of the trainees indicated that the PCATD improved their ability to perform Standard Terminal Arrival Route (STAR) procedures and the other three trainees were unable to rate this category as they had had not reached this skill level in instrument training. Krippendorff's alpha coefficient was calculated for inter rater reliability.

Krippendorff can also adjust for incomplete ratings. The value of α = 0.3487 indicates there was a low level of agreement between participants (see Table 6-5). This result may have been due to incomplete ratings and the small number of raters.

Table 6-5. Stage 1 PCATD Krippendorff's Alpha Coefficient (95% Confidence Interval)

	Alpha	LL95%CI	UL95%CI	Tasks	Raters
Ordinal	0 .3487	0.2022	0.4792	11	4-7

6.1.9.2 Heuristic Evaluation

After the cognitive walkthrough and task evaluations were completed, six statements relating to fidelity were presented to the trainees. These statements provided an evaluation of the PCATD and the user interface. At the end of each of the evaluations, they had to rate the statements using a Likert scale (e.g., *Strongly Disagree, Moderately Disagree, Neutral, Moderately Agree, and Strongly Agree*):

The statements and responses were as follows:

1. *The physical fidelity of the flight controls are at a high enough level in terms of accuracy and feedback response to conduct effective IFR/VFR training*

One pilot trainee Strongly Disagrees, three Moderately Disagree, and three Moderately Agree.

One trainee stated the "flight control sensitivity is still an issue." Another stated, "It was still extremely hard to maintain a set altitude and attitude for the simulated aircraft." This difficulty was attributed to the lack of feedback outputs from the flight controls rather than issues of latency.

2. *The resolution of the NZ terrain depicted in the PCATD is accurate enough to conduct effective IFR/VFR training?*

Three pilot trainees Moderately Disagree and four Moderately Agree.

Terrain resolution was a low priority for IFR training and was only really required for practicing instrument approaches where sighting the runway was required at minimum descent altitude (usually 250 feet). However, it was critical for individual pilot rehearsal of basic VFR manoeuvres.

3. The flight model characteristics of the Airtrainer CT4E developed for the RNZAF PCATD accurately match the real aircraft?

Three pilot trainees Moderately Disagree and four Moderately Agree.

This was a difficult aircraft to simulate, primarily because of its short wings and high engine power. It had poor gliding performance but was aerobatically nimble and had an impressive climb rate. However, for IFR task training in PCATD a more stable flight model is required to fly precision instrument approaches. Therefore, the flight model design was always a compromise between the demand for realism and the need for a pragmatic approach. In addition, there were some issues with airspeeds. The power an engine can produce is related to the RPM and manifold pressure (MAP). Power settings in the Airtrainer relate to MAP which is measured in inches on the MAP gauge. In the real aircraft with a selected RPM and MAP setting a certain speed is achieved flying straight and level (for example, 19" = 120 knots, 25" = 250 knots). Again, it is difficult to adjust the flight model to produce these exact outputs in all flight situations so more development work was required.

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to conduct effective IFR/VFR training?

Three pilot trainees Moderately Disagree, three Moderately Agree, and one Strongly Agrees.

The lack of field of view was a limitation but as most IFR task training was conducted in cloud this was not a major issue. Nevertheless, it became clear that the range of the field of view of the PCATD was an essential requirement for acceptance of the PCATD by the trainees.

5. The instrument panel depicted in the PCATD is realistic enough to conduct effective IFR/VFR training?
One pilot trainee Moderately Disagrees, five Moderately Agree, and one Strongly Agrees.

One trainee indicated that the NDB Aerial Direction Finder instrument was too accurate. This reflects the fact that in the real aircraft, the NDB beacon signal can suffer from atmospheric interference and the needle does swing back and forth, as it zeroes in on the Navaid. This is an example where the PCATD lacks realism and the effect that psychological fidelity has on the trainee. Five of the seven trainees had practiced VOR/VOR-DME, ILS, NDB, and VORTAC instrument approaches on the PCATD. The remaining two trainees had practiced at least two different types of approaches. The PCATD software demonstrated some versatility in being able to simulate a variety of instrument approaches with reasonable accuracy.

6. What other issues concerning the PCATD did you notice while performing the evaluation (Problems, concerns, improvements, limitations, etc.)?
No other issues were noted by the trainees.

6.1.10 Discussion

Ground based task training for advanced instrument flight procedures is usually attempted on high fidelity FTDs but the PCATD was assessed by the RNZAF flight instructors to be accurate enough for implementation in the PTS flight-training programme Before the inclusion of the PCATDs into the training curriculum the trainee pass rate for the final Instrument Rating Test was approximately 60%. After the introduction of the PCATDs, the pass rate improved markedly to 85%. Other factors may have contributed to this but the Commanding Officer of PTS stated that in his professional opinion the utilisation of the PCATDs for instrument training had a significant influence on the improved pass rates in the final instrument-rating test (A. Butt, personal communication, July 13, 2009).

The RNZAF PCATDs have provided a cost effective simulation platform for instrument procedure training especially in the areas of Navaid tracking, procedure turns, and holding patterns (N. Pedley, personal communication, July 10, 2012). However, one major limitation identified by the initial flight instructor evaluation and reinforced by student feedback, was the issue of fidelity of the flight controls. Because of budgetary restrictions, low cost COTS joysticks were incorporated into the PCATD development but with the advent of new technologies, this can now be addressed. In November 2011, a company released a MSFS compatible Hydraulic joystick, retailing for $NZ5000. This is relatively low cost compared to commercial FTD flight controls. These precision joysticks can provide force feedback of two Newton/metres (approximately one-Kilogram weight force) and can be moved twenty degrees in any direction (Paccus, 2011). This type of emerging technology could solve current flight-control fidelity limitations with the RNZAF PCATD in a cost effective manner.

Rantanen & Talleur (2005) completed a review of 19 studies from the past 56 years that have investigated transfer of training effectiveness in ground training devices. They concluded that the procedural aspects of instrument flight clearly make simulation an attractive training tool. Second, given the fidelity issues of current ground-based aviation trainers, their use for training of basic flying skills may be called into question. They argued training that focused specifically on the procedural aspect of flight and emergency management in ground-based trainers would result in higher transfer to the aircraft. Many lessons were learnt from the development of this first PCATD project. They include the following:

1. Despite some fidelity limitations, low cost PCATDs can be reasonably effective training aids when incorporated into a formal flight training programme.
2. If PCATD development is undertaken in close collaboration with the end users (flight instructors and pilot trainees) then the device can avoid obsolescence and continue to be an effective training aid for a long period, in this case it is still being used some years later.
3. These trainee pilots still preferred higher levels of fidelity despite numerous studies, (Lintern, et al., 1990; Noble, 2002; Taylor, et al., 2004) that demonstrate that successful transfer of training can occur with low fidelity PCATDs.

4. Due to the modular nature of the PCATD, upgrading hardware components as new technologies emerge is a versatile and effective way to rapidly improve the design.
5. An increasing proportion of the software that drives the PCATD subsystems is open-source (without copyright) which means the overall cost of software for the project continues to decrease significantly. This directly contrasts with most commercial FTDs where proprietary software and software maintenance represents a large cost component of the device.
6. PCATD development combined is strongly influenced by the demand for CAANZ certification. This provides an economic advantage for an FTO as it allows PCATD hours to be credited towards an Instrument Rating. This was not a requirement for the RNZAF PCATD and so its design could be focused more on improving training task transfer.
7. PCATDs can be used for individual training but are less effective if they are not incorporated in to the formal flight-training programme.
8. Pilot trainees continue to find innovative and imaginative ways to use these devices to improve their IFR/VFR skills.

6.2 Stage 2: Development of a PCATD for Helicopter IFR/VFR Training

6.2.1 Introduction

The Auckland Rescue Helicopter Trust (ARHT) was having difficulty in staffing a crew roster of eight pilots with instrument flight training, instrument recency training, and visual flight training in an efficient and cost effective manner. With only one helicopter, training requirements were adversely affecting the readiness and operational capability of the service. The helicopter used by the service was a modified MBB/Kawasaki BK.117 with a very high operating cost ($2000-$3000 per hour). The helicopter rescue service was designated as a charitable trust, and the continued operation of the service was wholly dependent on corporate and public donations. At the time, only one CAANZ certified commercial FTD provided helicopter flight training in NZ. The rescue service had taken the opportunity to evaluate this device but had found it too costly, too far away to access easily, and it simulated a different aircraft type. A possible solution to the problem was the development of a low cost PCATD to assist with IFR and VFR training tasks as the service did not have sufficient funds to purchase an expensive FTD. The helicopter pilots were required to obtain a valid instrument rating for the helicopter, actively maintain that rating, and complete an annual instrument competency test. To fulfil CAANZ currency requirements they also had to complete three hours of instrument flight training (at least one hour in the aircraft) and complete three published instrument flight procedures (at least two hours in the aircraft) (CAANZ, 2011d). In addition, as well as standard VFR training, a number of unique VFR rehearsal tasks had to be undertaken on a regular basis. These included hovering, emergency autorotation, winching, landing in confined areas, using Night Sun Floodlight technology, using Night Vision Goggles in night flying operations, and using TracMap GPS technology for flying search patterns. At the time, due to the lack of a flight simulator, all of the procedural training for these special VFR tasks had to be completed in the helicopter.

6.2.2 Background

The Auckland Rescue Helicopter Trust's origins date back to the establishment of the Rescue Helicopter Service in 1970. In 1990 a Charitable Trust was formed and the primary aim of the Trust was to provide and develop a highly efficient aero medical service for the benefit of the community. The rescue helicopter service is now in its 40th year of operation and is the only rescue service in New Zealand that operates 24 hours a day, 365 days a year. The service covers a region that has more than 1.5 million residents and visitors. In 2000 ARHT's outstanding contribution was recognised by the world "Association of Aeromedical Services" when it was presented with an award for 10,000 accident free missions. The rescue service has a current fleet consists of two MBB/Kawasaki BK.117 Helicopters (a second helicopter was acquired in 2011) used for search and rescue operations. (ARHT, 2012).

6.2.3 Literature Review

There has been only limited research on helicopter transfer for training. Hays, Jacobs, Prince, & Salas (1992) conducted a meta-analytic review of training transfer studies from a total of 247 journal articles and technical reports. They found 26 experiments (19 involving jet aircraft and only 7 involving helicopters) that provided enough data for statistical meta-analysis. The research indicated that simulation consistently produced improvements in performance by jet pilots compared with training in the aircraft only. However, the analysis found only a small number of helicopter studies, and no definite conclusions could be made about the effectiveness of simulators for helicopter training. The small number of relevant helicopter studies provided a limited knowledge base from which to develop future rotary wing transfer of training research. A few early research contributors investigated other training roles for PC-based helicopter training devices. Bowers, Salas, Prince, and Brannick (1992) discussed the use of a helicopter-gunship simulation as a potentially useful tool for researching team coordination and performance. Two-person teams were asked to fly the simulator together while researchers observed their communication patterns. They found several advantages in using a PC-based simulator as an experimental platform for studying team processes:

1. The technology is relatively low cost;
2. It has the required characteristics necessary for team research (e.g., two or more subjects, interdependency, and coordination requirements);
3. It provides increased experimental control of independent variables.

Bone & Lintern (1999) tested whether rehearsal in a PCATD based on a helicopter flight model could enhance a pilot's preparation for navigation through unfamiliar terrain. There were 36 active pilots participants (31 men, 5 women). Their flight experience was a median of 272.5 hours with a median of 80 hours of cross-country navigation experience. The results of this study indicated that unguided rehearsal in a flight simulator was superior to map study for developing the critical skills needed for aircraft navigation. In the late 90's, most helicopter PCATD transfer of training research was conducted by the Army Research Institute for the Behavioural and Social Sciences (ARI) Rotary Wing Aviation Research Unit at Fort Rucker, Alabama. A series of training transfer experiments were conducted to evaluate the feasibility and practicality of training Army Initial Entry Rotary Wing (IERW) students in ab-initio helicopter piloting skills using low-cost simulation and computer-automated training. In four of the training transfer studies, eight VFR manoeuvres were selected for evaluation: take-off to hover; hover taxi; hovering urns; hovering autorotation; normal take-off; traffic pattern; normal approach; and landing from hover.

Experiment 1 was an evaluation of the simulator, to investigate transfer of training. Experiments 2 and 3 were conventional transfer of training experiments, employing ab-initio pilot trainees. Experiment 4 was a substitution experiment in which seven hours of helicopter aircraft time was replaced with nine hours of simulator time. These four studies produced a number of findings about the effectiveness of PCATDs for helicopter training (Stewart II, Dohme, & Nullmeyer, 1999):

1. Low-cost simulation is effective in training ab-initio students in the basic VFR flight control skills.
2. Training in low-cost visual simulators can substitute for aircraft training with no significant loss in trainee performance. However, it may be necessary to provide more maneuver iterations in the simulator than in the aircraft to meet the same training standards.
3. Training in a low-cost simulator can demonstrate positive transfer of training (TOT) to the aircraft, if the out-of-the-cockpit views and the aerodynamic flight model provide the pilot trainees with moderate fidelity.
4. An automated, adaptive, specifically designed simulator can provide significant benefit to the training of hovering flight skills at very low cost.
5. Improvements in the quality of the out-the-window visual scene such as more polygons displayed, textured surfaces, and faster scene update rates resulted in greater training transfer.

In a follow-up study, Stewart II, Barker, Weiler, Bonham, and Johnson (2001) compared a motion simulator, the 2B24 Synthetic Flight Training System[13], used for the Army Initial Entry Rotary Wing (IERW) IFR training with a PC-based simulator, the Frasca 342 Primary Skills Trainer[14].Thirty-eight pilot students were randomly assigned to an experimental or control group. Both groups completed 30 hours of simulator training(one

[13] The 2B24 Synthetic Flight Training System (SFTS) simulated the cockpit of a UH-1 Army Iroquois coupled with a hydraulic motion platform but no visual display(Stewart, 2001).

[14] The Frasca 342 Helicopter FTD is configured to represent a light single piston/turbine engine powered helicopter such as the Bell 206,(Frasca, 2011b)

group in the SB24 and one in the PCATD) and 20 hours in the TH-67[15] aircraft. The research indicated that, it did not seem to matter which simulation device was used, pilot trainees were able to complete instrument training successfully. The results demonstrated the advantages of practicing IFR skills in a less costly, fixed base PCATD. Three additional studies that investigated the training effectiveness of PCATDS for helicopter training were chosen for this review because they used either MSFSs or X-Planes as the primary simulation engine. These studies investigated a range of issues concerning PCATDs that included IFR & VFR task training, FOV, terrain fidelity, motion, and situational awareness.

Proctor Pank and Donovan (2004) considered the usability and suitability of a PC-gamer approach for simulation of multi-ship helicopter operations. Twenty participants were split up into two man teams and to conduct multi-ship helicopter operations, a suite of two station helicopter simulators were created. The PCATD design was low-cost and low-fidelity and as a result, an off-the-shelf approach was taken towards sourcing the necessary components. The PCATDs were then used in a study of inter-cockpit team situational awareness and task performance. MSFS 2000 was the software used for inter-cockpit team training and installed on a standard PC with a single 19-inch CRT monitor.

A third party scenery package depicting the Canadian Rockies was also added to the default MSFS scenery. Three-dimensional features at take-off, landing, and interaction points were created with the MSFS 2000's graphical editor. One of the challenges of the PCATD design was providing the realistic outside-cockpit visual cues. These cues would normally be obtained through peripheral vision or by turning one's head. This was achieved by using the "China Hat" a spring-loaded multidirectional switch mounted on top of a joystick. The China Hat when programmed with the correct MSFS view commands enables the pilot to rotate the cockpit view and pan through the surrounding scene. This software technique increases the field of view that is normally limited by the size of the monitor.

[15] The Army's TH-67 New Training Helicopter (NTH) is a Bell Model 206B Jet Ranger III built by Bell Helicopter Textron Inc. Its function is to replace existing UH-1 Huey being used for training Initial Entry Rotary Wing students.(GlobalSecurity.org, 2010)

The development of the ARHT PCATD incorporated some of the low cost innovations created in the Proctor's et al study. These included the use of highly detailed third party scenery packages, the adoption of the China Hat, and MSFS software generated outside cockpit views.

Johnson and Stewart (2005) investigated the use of simulation for IERW training. This PCATD was developed by Desk Top Simulators L.L.C and was designated as a Rapidly Transferable Cockpit (RTC). Several PCATDs were used for this study. The visual display monitor measured 28 inches (71 cm.) diagonally. The angular field of view of this screen from a normal sitting position was 43 degrees (horizontal) by 34 degrees (vertical). This CRT screen had a resolution of 768 pixels horizontally by 1024 lines vertically(see Fig.6-4). The PCATD used MSFS 2000 with a Bell 206B Jet Ranger flight model

Figure 6-4. Desk Top Simulators L.L.C. Helicopter PCATD Screen Display (Facsimile)

Source: (Johnson & Stewart II, 2005)- Utility of a Personal Computer-Based Aviation Training Device for Helicopter Flight Training. *International Journal of Applied Aviation Studies, 5*(2), 21.

Sixteen military aviators (six flight instructors and ten student helicopter pilots) evaluated the training effectiveness of a PCATD running MSFS 2000 software. The findings indicated there was high level of agreement between instructors and students that the

PCATD could support IFR skills training. Evaluators stated that both instrument flight tasks and navigation tasks could be trained to some extent using it. However, they found it had little scope for VFR training especially tasks that required hovering as a part of the flight manoeuvres. The conclusion was that helicopter pilots require good out-the-window visual cues to determine height above terrain for a wide range of VFR tasks such as hovering, approach, and autorotation. Due to these visual limitations, especially the lack of peripheral vision in the display, none of the evaluators could achieve a stable hover (Johnson & Stewart II, 2005).

Proctor, Bauer, and Lucario (2007) investigated the effects of limited visual fidelity, FOV, and motion in relation to VFR task performance on PCATDs. One PCATD had an enclosed cockpit attached to a motion platform whereas the desktop PCATD was fixed base. Forty-five helicopter pilots participated in the study and they were assigned to one of three training configurations Cabin with Motion, Cabin with No Motion, and Desktop. The three assigned groups had the same number of beginner, intermediate, and advanced level pilots The VFR task assigned to the participants was complex and involved a search and rescue mission with turbulent weather conditions. At the same time, the research considered the interface usability, flight model fidelity, and simulation sufficiency for task learning.

One of the PCATDs in the Proctor, Bauer, and Lucario (2007) study was a generic dual controls helicopter-training device with fully enclosed cockpit and 2DOF motion platform. The display system was a 60-inch (diagonal) rear projection display set at 1024 x 768-display resolution. The second PCATD was a PC-based desktop trainer with a single joystick, chair, collective and pedals. The display system was a 19-inch CRT monitor set at 1024 x768-display resolution. The choice of software was influenced at the time by its low cost, and the recent FAA certification of a full motion simulator using X-Planes as its primary software engine (Kreider, 2002). The results of the study indicated that there were was no statistically significant difference in performance between participants who completed the task on the motion platform compared to those who were allocated to the no-motion platform. However, group size was relatively small (15) so experimental power may have been low.

The findings of the study noted that the difference in FOV between the Desktop PCATD and Cockpit PCATD was a factor in the participants' successful performance of the search and rescue mission. Finally, performance in both the Cockpit PCATD and the Desktop configuration was affected by the level of terrain fidelity generated by the X-Planes software. Participants commented that greater levels of fidelity of terrain were required in order to judge speed and distance more accurately. Only six studies in the research environment were identified that used PCATD based technology combined with MSFS or X-Planes software and focused on helicopter flight training.

These studies had various research objectives, which included aircrew coordination, navigation rehearsal, IFR & VFR tasks, and comparisons of training transfer effectiveness between FTDs and PCATDs. The number of participants was relatively low but indicative of these types of studies where most subjects are usually qualified pilots. Therefore, due to the low number of studies and reduced participation, the results of each study must be treated with some caution. In light of the rapid developments in PCATD technology and fidelity in the last few years, this is still an area of research that could be explored in more depth.

6.2.4 Research Gap

Many studies have investigated the training transfer of PCATDs for fixed wing aircraft (Lintern, et al., 1997; Rogers, et al., 2009; Taylor, et al., 2004) but only a few have examined PCATD training for helicopter pilots (Stewart II, et al., 2001; Stewart II., et al., 2008). The literature review identified a number of issues still to be resolved in the use of PCATDs for helicopter training. These relate to fidelity of visual terrain, field of view, fidelity of flight controls, and flight model fidelity. The majority of helicopter operations require the pilots to fly VFR related tasks. The nature of these task emphasise the importance of visual cues. Whereas IFR operations emphasise the importance of fidelity of instrument panels, flight controls and flight models. For the current study, a relatively low cost helicopter PCATD ($30 000-$40 000) was designed and developed for IFR /VFR training to support the flying operations of the helicopter rescue service. The design of the low cost ARHT PCATD incorporated a number of advanced features. These included:

1. Increased fidelity of the terrain resolution (20m elevation mesh resolution);
2. An increase in FOV (90 degrees) from the Stage 1 project which had an FOV of 70 degrees;
3. Improved accuracy of the Bell 206 and BK 117 helicopter flight models, with the inclusion of advanced helicopter aerodynamics (Flapback, Vortex Ring, and Autorotation).

In addition, instrument panel simulation and fidelity was significantly improved by the development of more robust software code and the use of multi-screen displays. The improvements in visual screen size, terrain fidelity, instrument panel fidelity and flight modelling meant the ARHT PCATD was superior, in terms of fidelity, to the research based PCATDs discussed in the literature review. In addition, many of the improved features (e.g. high resolution terrain, advanced aerodynamic flight modelling, and 3D object generation) also gave the ARHT PCATD a distinct advantage in terms of training capability over more expensive FTDs that were commercially available at the time (Elite, 2010; Frasca, 2011b).

6.2.5 Development of the ARHT PCATD

In Stage 1, a fixed wing PCATD for IFR/VFR flight training was developed, and in Stage 3, a fixed wing VFR PCATD was developed soon after the commencement of the Stage 2 project. The development programmes of Stage 2 & 3 overlapped for some time. The Stage 2 project required a radically new PCATD design as rotary wing simulation was markedly different to fixed wing simulation. However, a number of common themes remained such as the financial constraints of low cost design, and the need for pilot input and evaluation during the development phase. Also, each stage was characterised by the implementation of incremental improvements in visual display technology and flight model accuracy. The design process developed for each stage was readily transferable to subsequent PCATD projects.

6.2.5.1 Project Development

Fortunately, even though the MSFS software was primarily designed to simulate fixed wing aircraft it also contained an accurate helicopter flight model. Accordingly, MSFS became the logical choice as the primary software engine for the Stage 2 development of a helicopter PCATD. Two low cost technologies that were transferred to the helicopter PCATD from the Stage 1 development programme were the digital displays of instrument gauges, and the use of commercial-off-the-shelf (COTS) flight controls. A helicopter PCATD is more complex than a general aviation fixed wing PCATD (Stewart II, Dohme, & Nullmeyer, 2002; Stewart II., et al., 2008). A helicopter PCATD requires an accurate simulation of complex flight controls, helicopter flight modelling, and helicopter aerodynamics In this case the helicopter also had a mixture of analogue, and glass-cockpit flight instrumentation that had to be replicated as accurately as possible. The PCATD design also specified a level of fidelity and conformity that could achieve NZ CAA instrument-flight training certification.

Certification would allow the rescue service the flexibility to direct some IFR assessments and recency training from the aircraft to the PCATD, at a considerable cost saving to the organisation. Two factors increased the project completion time. The helicopter PCATD was constructed at the helicopter rescue centre, which was 500 km from where the project designer was based. In addition, project funding from corporate sponsors was spread over several years. Initially, customised COTS Helicopter flight controls were sourced from overseas and these were installed into a desktop computer with a single CRT display.

This simple prototype was developed as a proof of concept and was used by the rescue pilots on an informal basis for training and evaluation. The continued utilisation of the desktop PC prototype reinforced its training potential with the pilots and additional funding was sought from the rescue service trust to upgrade the prototype. When the funding was approved, the decision was made to commence a formal project to develop a fully customised Helicopter PCATD for IFR/VFR training. After planning meetings with the senior pilots and senior management of the rescue service, a PCATD helicopter design was approved. Subsequently a project plan was drafted and implemented. The PCATD was constructed and during this time, feedback and suggestions were elicited from the pilots. Their recommendations were progressively implemented to improve the design of the operational PCATD (see Fig. 6-5). The rescue service pilots commenced IFR/VFR training in 2008 with the PCATD, and although not CAANZ certified at this point it was used extensively for training purposes. Continual revisions and improvements to the PCATD software and hardware were requested by the senior pilots until formal CAANZ certification was achieved in September 2010 (CAANZ ARHT, 2010). A major issue with the development of the PCATD was that it did suffer from project creep. There was a gradual increase in the overall training objectives of the PCATD by the rescue service, which extended project deadlines and stretched project resources.

Figure 6-5. AHRT HELISIM PCATD Cockpit Construction

6.2.5.2 CAANZ Certification Issues

Unexpected difficulties with compiling instrument approach data, software maintenance, hardware redundancy, and training documentation had to be resolved before CAANZ certification was finally achieved. Instrument approach data is updated by NZ Airways Corporation on a regular basis to accommodate changing airport infrastructure, safety issues, and environmental concerns (e.g., noise pollution) (IAP, 2010).

The MSFS software has an internal global instrument approach database that was updated in 2006 but no subsequent updates have been implemented since then (Microsoft, 2010). This meant that the NZ instrument approaches had to be updated in MSFS by using third party software tools, which was quite a labour intensive task. The PCATD also uses a number of third party software packages and most have regular system updates (Dowson, 2012). As terrain fidelity was improved, the graphic processing power of the original computer was not powerful enough to drive the visual displays of the PCATD. This meant the original computer had to be replaced with a more powerful PC. To achieve CAANZ certification the helicopter rescue service also had to reproduce a Standard Operating Procedures Manual and a comprehensive training syllabus (CAANZ ARHT, 2010). The training syllabus had to describe exactly how the PCATD was to be used within the training programme. Because all of the pilots worked intensive operational shifts there was little time for document writing. The rescue service eventually released a pilot from most of his operational duties so he could concentrate on document writing and completion (D. Walley, personal communication, 8 July 2012).

6.2.5.3 Visual Fidelity

For the IFR/VFR training role, emphasis was placed on maximising the ARHT PCATD's visual fidelity by expanding the field of view (FOV), and increasing the resolution of the visual terrain. When the pilots had used the prototype for informal training, they had already expressed reservations about the field of view of the visual display. Also a number of the studies had recommended extended FOV for effective VFR flight training (Keller, Schnell, Lemos, Glaab, & Parrish, 2003; Proctor, et al., 2007). The design incorporated a number of commercial off-the-shelf products, which reduced development and maintenance costs. Several innovative features were also developed for the project. Multi-screen instrument displays were created by the use of first generation, graphic-display-splitter technology. The adoption of this low cost technology meant PCATDs could match the multi-screen displays of much more expensive FTDs. The enhanced visual terrain detail, with a horizontal accuracy of 20-50 metres and vertical accuracy of 20-40 metres surpassed the terrain fidelity of most commercial FTDs used for flight training in NZ. The use of MSFS also provided access to a global database of customised airfields, aircraft, instrument panels and flight models as well as third party software tools.

Unlike the direct view technologies used in Stages 1 and 3, the ARHT PCATD was designed to use a data projection visual system. The primary reason for using projection technology was its capability to display a large horizontal and vertical field of view. Vertical field of view is crucial for pilots to simulate helicopter VFR manoeuvres such as autorotation and hovering (Keller, et al., 2003). A provision was made in the PCATD visual display system to allow for the installation of two additional data projection systems to increase FOV to even higher levels. The PCATD was installed into a transportable trailer and the two sides of the trailer were hinged so that they could be opened up on a forty-five degree angle. This would allow additional projection screens to be mounted on the sidewalls of the trailer. When combined with the front screen this would provide a very large display surface with a FOV of almost 170 degrees.

However, due to budgetary constraints this new display feature was not implemented. The intention of the rescue service is to proceed with this visual display upgrade in the near future when sufficient funds could be allocated to the project. A comparison of the visual display technologies of the PCATDs identified in the literature review and the ARHT PCATD are outlined in Table 6-6. The FOV of the various PCATDs varied considerably, from 19 inches to 120 inches. Most of these studies recommended that PCATDs use the largest screen size as practicable, and the highest visual display resolution as possible, to achieve effective VFR task training.

Table 6-6. Comparison of PCATD Visual Displays

PCATD Research	Visual Display FOV	Screen Resolution
Proctor, Panko, & Donovan (2004)	19 inch Monitor	1024 x768
ARHT PCATD	8 ft. x 6 ft. data projection screen – 120 inch diagonal	1280 x 1024
Johnson and Stewart (2005)	28 inch monitor (diagonal)	1024 x768
Proctor, Bauer, & Lucario (2007)	PCATD 1 – 60 inch (diagonal) rear-projection & PCATD 2 – 19 inch monitor	1024 x768

The advantage of projection systems is that they can generate the image from the rear or front of the screen and display images over a wide area. These systems are becoming more popular for PCATDs because displays with large fields of view can be expensive when they are generated with other forms of display technology (Lee, 2005). The ARHT display was capable of displaying an FOV of 90 degrees as well as a relatively high resolution (1280 x 1024 pixels); a superior level of visual fidelity compared to other PCATDs listed in Table 6-6. However, projecting an image over a wide screen without a high level of display resolution reduces the spatial resolution. The spatial resolution is directly measured by calculating the Pixels per Inch (PPI) of the display. The PPI of the ARHT PCATD was lower than the 102 PPI value recommended by Keller et al (2003). However, this limitation was partially compensated by a larger screen size and increased terrain fidelity.

6.2.5.4 Helicopter Flight Control Fidelity

At the time of the development of the ARHT PCATD, commercial-off-the-shelf, high fidelity helicopter flight controls were virtually impossible to procure. A company was eventually located in the United Kingdom. It was one of only a few manufacturers in the world producing relatively low cost COTS helicopter flight controls for use in PCATDs. These flight controls were robust, well-engineered, and had a relatively high level of fidelity (RC Simulations, 2005). In addition, the dual flight controls (Collective, Cyclic Stick, and Anti-Torque Pedals) were enhanced by the subsequent purchase of a fully functional Twist Grip throttle so that the complex Bell 206/BK117. Helicopter engine start up sequence could be fully simulated. The use of COTS flight controls reduced development time significantly.

Developing customised controls using project resources would have been a very difficult task and would have required extensive prototyping. At the time only one certified FTD Helicopter (Waikato Rescue, 2012) was in operation in NZ. This was the first time this type of COTS flight control was incorporated into a PCATD used for search and rescue helicopter training in NZ. One issue with the flight controls was sensitivity, a problem that had surfaced in Stage 1 and the concurrent Stage 3 development. Sensitivity of flight controls relates to the amount of movement required to initiate a corresponding response of the flight surfaces.

Digital flight controls are very accurate but have no feedback response or hydraulic pressure as most real aircraft flight controls do. Small movements of digital controls can provide large movements in the flight controls surfaces (i.e. ailerons, elevators, and rudders) of the simulated aircraft. This is one of the major limitations in low cost PCATDs but can be compensated for by student pilots learning to use fine motor-control hand movements, trim controls and the autopilot. Also, flight control sensitivity was able to be reduced but not totally eliminated by using software filters such as FSUIPC to increase improve response rates and lower the sensitivity (Dowson, 2012).

6.2.5.5 Helicopter Flight Models

One aspect of instructor feedback during PCATD development related to the need for the helicopter flight model to replicate complex helicopter aerodynamics. The MSFS helicopter flight model used in the ARHT PCATD could accurately simulate standard flight phenomena such as hovering and translational lift. However, helicopter aerodynamics is very complex and certain hazardous phenomena have to be simulated so that pilots can be trained to recognise them and apply corrective flight control procedures. These helicopter aerodynamic phenomena include vortex ring state[16], retreating blade stall[17], and autorotation.[18] Many of the PCATDs outlined in the literature review did not incorporate advanced helicopter aerodynamic features in their flight model (Stewart II, et al., 2002). This was due to the limitations of the helicopter flight model in MSFS that only simulated basic helicopter aerodynamics, and the complexity and cost of developing advanced aerodynamic features. The design approach for the ARHT PCATD was to use and modify new COTS software that simulated advanced helicopter system and flight dynamics (DODOSIM, 2005). Again, this low cost approach was radically different to

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[16] The vortex ring state, is a hazardous condition that may arise in helicopter flight, when a vortex ring system engulfs the rotor causing severe loss of lift.(FAA, 2001)

[17] Retreating blade stall is a dangerous flight condition in helicopters where the rotor blade rotating away from the direction of flight stalls. The stall is caused by excessive angle of attack, (FAA, 2001)

[18] Autorotation is the state of flight where the main rotor system of a helicopter is being turned by the action of air moving up through the rotor as with an auto gyro, rather than engine power driving the rotor, (FAA, 2001)

other commercially available helicopter PCATDs that are driven by proprietary software and hardware developed internally by the respective companies (Elite, 2012b; Frasca, 2011b). Three types of helicopter flight models were developed:

1. A generic Bell Jet Ranger 206 flight model with a realistic start-up sequence[19]. It also included simulated advanced aerodynamics (i.e. vortex ring state, retreating blade stall, and autorotation). This flight model was difficult to fly in the PCATD but represented a very accurate simulation of the inherently unstable flight dynamics of a modern helicopter. This model was used specifically to rehearse the complex startup sequence but required the additional development of configuration files to work correctly with the PCATD software architecture. Additional features such as annunciator warning lights, circuit breakers, throttle release stops, audio warnings, and turbine-outlet temperature warning lights were also simulated (DODOSIM, 2005). By using this advanced flight model, helicopter pilots could recognise hazardous situations such as vortex ring state in the PCATD and rehearse the correct procedures to recover from them.
2. A second flight model of a BK 117 was developed that provided increased stability in the roll, pitch, and yaw axis. The flight modelling characteristics of the BK 117 were based on the default MSFS Bell Jet Ranger flight model. This model required extensive modification to simulate the twin-engine power envelope of the BK 117. This helicopter model did not include the start-up sequence module or advanced VFR manoeuvres as it was used specifically to practice IFR manoeuvres and IFR approaches. The helicopter pilots required more stability so that they could fly the instrument approaches and descent profiles more accurately. In these IFR sessions, the helicopter was usually positioned on the approach path at altitude, and therefore the start-up procedure was not required.

[19] A turbine engine helicopter can have a major engine malfunction if the start-up sequence is not correctly followed, and other environmental conditions are not compensated for. A faulty start up sequence can potentially cause engine damage costing thousands of dollars to repair.

3. A third flight model BK 117 was developed that did not include the lengthy startup sequence but included the basic helicopter flight parameters and one advanced helicopter aerodynamic (autorotation). This model was less aerodynamically stable than the second flight model and was used by the pilots for rehearsing standard VFR maneuvers and in particular the autorotation procedure. The autorotation maneuver is a critical procedure that is carried out in case of engine failure in the real aircraft. This meant that pilots could automatically start the helicopter (avoiding the lengthy and time-consuming startup sequence) and quickly practice VFR maneuvers such as hovering or circuits.

The use of different helicopter flight models to suit different training tasks was a design technique that gave the low cost ARHT PCATD a significant degree of flexibility for training purposes The helicopter pilots were able to choose the appropriate helicopter visual and flight model, coupled with a particular flight-training scenario at the commencement of each training session (see Fig.6-6). This method had not been attempted before in PCATD development. Commercial FTDs that simulated several different aircraft or flight models in the one device were not developed until considerably later (Frasca, 2007; Redbird, 2010).

Figure 6-6. Example of Auckland Rescue T BK 117 Helicopter Visual Repaint

Source: (Reider, 2007)- Eurocopter Kawasaki MBB BK 117 ZK-HHV. Retrieved from http://www.hovercontrol.com/cgi-bin/ifolio/imageFolio.cgi?action=view&link=FS9_Helicopter_Repaints&image=BK_117_Westpac.zip&img=0&search=kawasaki&cat=all&tt=zip&bool=and

6.2.5.6 Terrain Fidelity

A number of studies have examined the effect on VFR training after increasing terrain fidelity in PCATD visual displays (Kleiss, 1995; Mulder, et al., 2000; Padmos & Milders, 1992; Williams, 1993). Despite the fact that low levels of scene detail may not necessarily inhibit training transfer (Noble, 2002) there has been an increasing demand for higher levels of fidelity of terrain in flight simulation (VectorLandClass, 2011). Increased terrain fidelity is required for VFR helicopter flight training because most helicopter flying is conducted below five thousand feet. The default MSFS software is sold with a default 1200-metre terrain resolution. Because of the low level of the default resolution, many geographical features such as prominent buildings, rural roads, small streams, and valleys are not depicted in the MSFS default NZ scenery. At the beginning of the project, senior pilots at the rescue service had made a subjective assessment that the MSFS default terrain was not detailed enough for low-level helicopter search operations. A similar assessment about terrain detail had been made by pilots involved in the concurrent Stage 3 project.

Helicopter rescue operations are normally classified as VFR flights and are usually flown at low altitude (below 1000 ft.) where recognition of landmarks and geographic features is critical. A partial solution to improve the default MSFS scenery was to use a third party scenery package called NZ Roads & Rivers. This terrain upgrade was compatible with MSFS and displayed NZ topography at a scenery resolution of 20 metres horizontally (Stock, 2005). Many helipads used for training in the aircraft, were located in obscure areas such as small islands off the coast of NZ (e.g., Waiheke Island). Most of these helipads did not exist in the MSFS default NZ scenery or any compatible scenery package. Therefore these helipads and other significant landmarks had to be developed for the project (Reweti, et al., 2005).

The combination of high resolution terrain and 3D object scenery for the PCATD surpassed the scenery resolution produced by virtually all FTDs used for flight training in NZ at that time (Aerosoft, 2006; Elite, 2010; Frasca, 2006a, 2010, 2011a). Also a number of studies provided supporting evidence that high resolution scenery displays (Mulder, et al., 2000) can provide an advantage in VFR training transfer performance (Kleiss, 1995; Lintern, et al., 1997; Padmos & Milders, 1992).

6.2.5.7 Instrument Panel Fidelity

PCATDs identified in an extensive review of the literature used only single monitor displays for the instrument panel. That meant instrument gauges were quite small and hard to read. The development of the instrument display for the ARHT PCATD was a difficult challenge. For example, the helicopter pilots requested that the digital display of the gauges had to be the same size or larger than the real helicopter gauges. To achieve this, the gauges had to be displayed on more than one LCD monitor. Full flight simulators have the advantage of using powerful graphic technology which can split information from a single display and recombine it into separate visual channels (Barco Simulation, 2011), or this PCATD project, a low cost Matrox[20] Graphic Splitter Module was used to display a single digital instrument display across three networked LCD 19 inch monitors without loss in resolution or frame rate.

There were some limitations with this first generation technology, which had to be addressed. It could not display different resolutions on each screen and only supported a set resolution of 3072 x768 pixels. It required a re-configuration of the Windows desktop and extensive modification of the MSFS panel configuration files to work correctly. This first generation technology was not powerful enough to display out-of-the-cockpit views in conjunction with the graphic cards installed in the PCATD but was capable of updating less complex instrument displays (Matrox, 2005). In addition, to increase realism, black Perspex cut-out panels were overlaid over these monitors to enhance the perception of individual flight instruments (see Fig. 6-7). This low cost technique would not appear in FTDs like Frasca's Reconfigurable Helicopter FTD until 2008 (Frasca, 2008). Most legacy FTD manufacturers populated instrument panels with servo-driven replica flight instruments. Although more realistic they were more costly to maintain. This low cost digital instrument panel technique (using networked LCD monitors) was pioneered in this PCATD project but is now quite popular, and many commercial FTD manufacturers use it in their FTDs (Elite, 2012b; Redbird, 2012). An additional design requirement for the

[20] The Matrox company released a graphic card peripheral that could convert a single VGA input and split it to display in two monitors (Matrox, 2005).

ARHT PCATD was the insertion of switches and dials in their correct location on the instrument panel. These additional switches and dials had to be inserted into the Perspex panels with low profile switches and thin wiring looms to avoid contact with the monitors. A number of complex flight instrument gauges as well as the standard flight information gauges had to be simulated in the PCATD. The solution was to use low cost COTS hardware and software to reduce development time (Go Flight, 2010; PFC, 2012). Where suitable components did not exist then customised software/hardware interfaces had to be developed within the project.

Figure 6-7. Completed ARHT PCATD

Many of these software interface modules for MSFS had already been created in Stage 1 and only needed slight modifications for use in this project. MSFS has a database of several hundred flight instrument gauges (MSFS 2004 SDK, 2012). However, the more complex gauges required for the ARHT PCATD were not available in the MSFS database and these included the:

1. Garmin Global Navigation System (GNS) 430/530 Dual GPS Gauge;
2. Sandel SN3308 Electronic Flight Instrument System (EFIS)Gauge;
3. Garmin GMX 200 Moving Map Gauge.

The simulation of these instruments in MSFS was extremely difficult. To replicate the functionality of these sophisticated gauges without source code, and to make them compatible with MSFS by in-house development would have exceeded the total cost of the entire PCATD project. Fortunately, interest in low cost PCATD development was Germany and the USA were developing MSFS compatible gauges for the Microsoft flight simulation community. These companies were eventually able to replicate these complex gauges, make them compatible with MSFS, and sell them for less than $NZ100 each (Aerosoft, 2007; RealityXP, 2007). However, in the case of the Garmin GNS gauge there was a major limitation in simulating instrument flight procedures. It accessed the FS2004 internal global database of instrument approaches but the NZ data was incomplete (Microsoft, 2010).

Further software development was required to update the relevant instrument approaches including the NZ maps for the Moving Map Gauge (MSFS 2004 SDK, 2012). This updating process is a continual process as airports often change their runway instrument approach data for operational reasons. Special configuration files had to be created to ensure that the three gauges communicated with each other through a common protocol (Dowson, 2012) and displayed the navigational data in the correct format. The Sandel EFIS configuration was problematic at first but eventually its data display issues were resolved. By using these various software and hardware techniques, a high level of functional fidelity was achieved with the instrument panel of the ARHT PCATD). This level of fidelity easily matches the instrument display fidelity of more expensive commercial FTDs (Elite, 2012b).

6.2.5.8 Additional Design Features in the PCATD

The initial ARHT PCATD project design required the development of a number of additional features for training purposes and in particular, to satisfy the requirements for NZ CAA certification Additional features installed into the ARHT PCATD included a networked PC-based instructor station that could position the helicopter at any location, altitude, and speed. It could introduce weather, engine and instrument faults, display flight track, and record flight missions for later analysis. A flight track printer was used to print out flight tracks and flight data so an assessor could evaluate a pilot’s performance.

Finally, a radio/headset intercom system was also installed to make pilot-to-pilot communications more realistic.

An additional requirement by ARHT was that the PCATD had to be portable. The PCATD was designed so that it could be easily transported to other helicopter search and rescue centres in NZ that required it for training purposes (see Fig. 6-8). This PCATD was the first one to be located on a mobile platform with its own uninterruptible power supply (UPS) and electrical isolation safety system. The unit could be relocated for training in outlying units and for promotional purposes. When the mains power supply was difficult to access, it could be operated successfully with a portable power generator. Again, this would be the first PCATD developed in NZ that had the capability to be easily relocated to another FTO's location where training could take place.

Figure 6-8. ARHT PCATD Custom Trailer

6.2.5.9 Project Extension – TracMap GPS Interface

In 2010, a NZ based company TracMap Ltd. produced a portable GPS Search & Rescue Pattern Display Unit. A key component of this unit was the Aviation Search and Rescue system, which enabled the most effective search patterns to be created. This made the difficult task of allocating and accurately searching large areas significantly easier (TracMap GPS, 2011). The first system installed into a search and rescue helicopter was estimated to have reduced their flight time for searches by up to 50 per cent because of accurate flying of the search pattern, elimination of the requirement to re-fly areas to ensure complete coverage, and the ability to have a co-ordinated systematic approach to the search. This portable unit was inserted into the Auckland Rescue Trust helicopter and provided the pilots and aircrew with a very accurate and efficient graphical search pattern to follow.

Another feature of TracMap was that it recorded the GPS coordinates of the search patterns for training and audit purposes. In the past pilots would have to fly search patterns manually using compass bearings, and often would fly over the same search area twice or even miss sections of a search area. Also, they had no mechanism for recording search and rescue missions, which was now a statutory requirement. After the service purchased a portable TracMap GPS, pilots and aircrew required training on the device to operate it effectively. This training requirement created the impetus for an additional project to enhance the operational capability of the PCATD by the development of a software/hardware interface to link it to the new TracMap GPS Search & Rescue System (TracMap, 2011). In 2011, government departments who contracted helicopter rescue services (e.g. Police. Department of Conservation, Maritime NZ, & NZ Civil Defence) could now request flight-tracking data of search and rescue operations for audit purposes (Walley, D. personal communication, 20 July 2011).

A problem was that learning how to operate the device effectively could take up to ten hours per pilot and this was difficult and costly to accomplish in the helicopter. The solution was to interface the device with the ARHT PCATD. This meant pilots and aircrew could learn all the correct procedures to run the GPS in the less stressful environment of the PCATD but still simulate the operation of the device in real time. The TracMap GPS system was not designed to be compatible with MSFS software so communication protocols had to be created with original software code. This was the first time in the world that a TracMap GPS device had been successfully integrated with a PCATD using MSFS software (see Appendix F).

6.2.6 Evaluation of the ARHT PCATD

6.2.6.1 Introduction

The evaluation of the PCATD was driven by three main objectives:

1. Could the PCATD be used effectively for VFR helicopter training?
2. Could the PCATD be used effectively for IFR helicopter training?
3. Could the ARHT PCATD achieve CAANZ certification for IFR/VFR training?

CAANZ certification meant that the PCATD would become an approved device to provide cost effective instrument rating assessment, and instrument recency training. Certification would also provide external validation of the PCATD's overall fidelity for IFR/VFR training as well as aviation industry recognition of its fitness for purpose. An evaluation of the ARHT PCATD was undertaken by six helicopter pilots. However, not all pilots completed all of the evaluations due to time constraints, availability, or level of training. The number of pilots ranged from four to six for individual task evaluations.

The purpose of the evaluation was to determine how effective the PCATD was for IFR/VFR training tasks undertaken by the operational helicopter pilots working at the rescue service. Fifteen IFR/VFR tasks were selected for evaluation in the ARHT PCATD. A senior pilot classified these training tasks as the most relevant for evaluation in the PCATD. The rescue service pilots were experienced in flying the BK 117 helicopter. They were using the ARHT PCATD mainly for advanced VFR/IFR procedural training and most ab-initio training tasks were not as applicable. The ARHT PCATD evaluation was then compared with the results of a similar evaluation study conducted by Johnson and Stewart II (2005).

In this study six experienced helicopter pilots evaluated a PCATD's capability to train ab-initio students in seventy one unique IFR/VFR flight tasks (Johnson & Stewart II, 2005). Many of these tasks were at the primary training level and therefore were not included in the ARHT PCATD evaluation. However, Johnson & Stewart II's study evaluated at least thirty advanced IFR /VFR tasks and a subset of these was matched with the fifteen tasks chosen for the ARHT PCTAD evaluation. The two PCATDs being evaluated were similar in design, and both used MSFS as the simulation software engine. They also had similar flight controls but visual display fidelity, and instrument display fidelity was significantly different. The comparison was undertaken to determine similarities in the two evaluations and common issues or problems when designing and using PCATDs for helicopter IFR/VFR training.

6.2.6.2 Participants

At the time of the evaluation, the ARHT crew pilot roster was eight but this was eventually reduced to six due to operational and financial constraints. The demographic composition of the six pilots that completed the evaluation was as follows:

1. The pilots were male;
2. The pilots ages ranged from 32-64;
3. The pilots flight experience on the BK117 helicopter ranged from 150-3000 hours with a mean of 1060 hours (Median 985 hours);
4. Two pilots had previous experience flying in the military;
5. One pilot had previous experience flying for a commercial airline.

A summary of the helicopter pilots' current level of helicopter flight experience is outlined in Table 6-7:

Table 6-7. ARHT Pilots - Aircraft & PCATD Currency Training Experience

Pilot Number	Total Flight Training Time (Aircraft) –Hrs.	Total IFR Time (Aircraft) Hrs.	Total PCATD Evaluation Hrs.
1	3000	100	10
2	470	40	15
3	1500	100	20
4	180	20	20
5	150	10	20
6	1800	200	10
Median	985	70	17.5

6.2.6.3 PCATD IFR/VFR Task & Fidelity Survey by ARHT Pilots

The helicopter pilots were selected for the evaluation because they were the primary users of the ARHT PCATD. The evaluation took place over a two-month period. They completed a task evaluation consisting of fifteen IFR/VFR procedural tasks, which could be completed independently or combined into a more complex procedure such as an instrument approach. Each task was allocated thirty minutes but participants could repeat the task until they achieved mastery.

This evaluation process was followed by a heuristic evaluation, which required feedback/assessment on seven questions related to the user interface and fidelity). This evaluation process was co-ordinated by a senior pilot at the rescue service. The training tasks could be completed as part of a training phase (e.g. full instrument approach) or as a stand-alone exercise. In the first phase, the pilots practiced fifteen IFR/VFR procedural tasks listed on the evaluation sheet, in the PCATD using a BK 117 flight model. There was no specific time limit but they could practice the IFR/VFR procedure until they completed it successfully. Some procedures can take a significant amount of time to evaluate so all of the pilots logged at least ten hours of evaluation time on the PCATD. This was sufficient time to practice and evaluate the various IFR/VFR tasks either in combination or individually. In the second phase, the pilots rated the user interface and fidelity of the PCATD. Comments and observations made by the pilots during their cognitive walkthrough and heuristic evaluations were also recorded.

6.2.6.4 Cognitive Walkthrough

The helicopter rescue pilots were required to complete a cognitive walkthrough by practicing fifteen different IFR/VFR tasks in the PCATD in any sequence. The fifteen tasks had been chosen by:

1. Reference to the (Johnson & Stewart II, 2005) study which evaluated seventy IFR/VFR training tasks. However, the majority of these tasks related to ab-initio training and many were considered not relevant to the advanced IFR/VFR training undertaken by the helicopter rescue pilots.

2. Consultation with the senior pilot of the rescue service to establish which training tasks on the PCATD were the most critical for the pilots' operational readiness.
3. Including tasks evaluated in Stage 1 and Stage 3 for continuity, and comparison of ratings of similar flight training tasks.

The IFR/VFR tasks were identical to those ones evaluated in Stage 1 (see Section 6.1.8) with the addition of four tasks specifically related to VFR helicopter procedures. These additional tasks were:

1. Circuits (VFR). This task involves performing a normal VFR circuit pattern at an airfield in a helicopter;
2. Navigation (VFR). This task involves performing a cross country navigation exercise in a helicopter;
3. Overhead Rejoin (VFR). This task involves completing a standard overhead rejoin procedure in a helicopter;
4. Hovering (VFR). This task involves placing the helicopter in a stable hover.

At the end of each of each of the fifteen assessments of the IFR/VFR tasks, the pilots had to rate the following statement:

Practicing this particular IFR/VFR flight procedure or manoeuvre in the PCATD can improve proficiency in the aircraft.

A Likert scale was used that provided a range of responses that measured the respondent's intensity of feeling concerning the statement. A decision was made to make it a five point scale which was identical to the scale used in related studies (Johnson & Stewart II, 2005; Stewart, 2001). The response/evaluation categories were *Strongly Disagree* - rated 0, *Moderately Disagree* - rated 1, *Neutral* – rated 2, *Moderately Agree* - rated 3, *Strongly Agree* - rated 4. One non-scoring category was included, *Unable to Rate* - where the evaluator had not reached a sufficient level of expertise to rate the task or was unavailable.

6.2.6.5 Heuristic Evaluation

The task evaluation was followed by a heuristic evaluation where the participants had to evaluate six statements that related to the user interface and level of fidelity of the PCATD. The seventh statement was open-ended where they could express any concerns or suggestions about the PCATD, and how the design could be improved. For the sake of consistency, the helicopter pilots were required to respond using the same five point Likert scale used in the task evaluations (e.g., *Strongly Disagree, Moderately Disagree, Neutral, Moderately Agree, Strongly Agree*). The statements that were rated by the pilots were the same as those used in the heuristic evaluations conducted in Stage 1 except for the inclusion of an additional statement. The additional sixth statement was specific to the ARHT PCATD, "The TracMap training interface in the PCATD is realistic enough to replace TracMap training in the helicopter."

6.2.7 Results

The results are presented in three parts. First, the results from the task evaluations of the PCATD in relation to the IFR/VFR tasks are listed. Then statistics (Mean & Standard Deviation) were used to analyse the fifteen task results. Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha can cope with any number of evaluators, incomplete data, and adjusts itself to small sample sizes (Krippendorff, 2004). Then ARHT task evaluations were compared with the matching task evaluations in the Johnson & Stewart (2005) study. Finally, the six heuristic evaluations of the user interface and fidelity of the PCATD were described qualitatively, including comments made by the helicopter rescue pilots.

6.2.7.1 ARHT Task Evaluation

The fifteen tasks were a mix of IFR and VFR procedures. There were three basic tasks and twelve advanced tasks that were evaluated, and the results are listed in Table 6-8. Overall, the results indicated that the pilots' assessment of the effectiveness of the PCATD produced a positive evaluation for twelve of the IFR/VFR tasks. Three of the five pilots indicated no improvement in circuits or overhead-rejoin tasks. All six pilots indicated no improvement in hovering. This was a strong indication from the pilots that there were still some issues with the visual display capabilities of the PCATD. advanced VFR procedures require the PCATD to provide good peripheral vision for the out of cockpit views to enable the pilots to execute these manoeuvres accurately. Four of the pilots indicated that the PCATD improved their ability to perform Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) procedures.

Finally, Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha coefficient was calculated for inter rater reliability, and reliability of coding. Krippendorff can also adjust for missing ratings, which was the case here. The value of $\alpha = 0.1752$ indicates there was only a small level of agreement between participants (see Table 6-9). This result may have been due to incomplete data and the small number of raters.

Table 6-8. Pilot Ratings for Practical Evaluation of IFR/VFR Tasks

IFR/VFR Flight Tasks (Basic & Advanced)	No. of Participants	Mean (0-4)	Standard Deviation
Instrument Scan (IFR/VFR)-Basic	6	2.5	1.9
Airspeed Control (IFR/VFR-Basic	6	2.3	1.6
Altitude Control (IFR/VFR)-Basic	6	2.6	1.5
Navaid Tracking(IFR/VFR)-Adv	6	3.3	1.2
Procedure Turns (IFR/VFR) –Adv	6	3	1.1
Holding Patterns(IFR/VFR)-Adv	6	3	1.1
Intercept Localiser(IFR)-Adv	6	3.3	1.2
Intercept Glide Slope(IFR)-Adv	6	3.3	1.2
Missed Approach(IFR)-Adv	6	3.2	1.2
SID Rehearsal(IFR)-Adv	5	3.0	1.7
STAR Rehearsal (IFR)-Adv	4	3.3	0.96
Navigation (VFR)- Adv	6	3	1.1
Circuits (VFR)- Adv	5	1.2	0.8
Overhead Rejoin(VFR)- Adv	5	1.2	0.8
Hovering(VFR)- Adv	6	0.8	1.4

Table 6-9. Stage 2 PCATD Krippendorff's Alpha Coefficient (95% Confidence Interval)

	Alpha	LL95%CI	UL95%CI	Tasks	Raters
Ordinal	0.1752	0.0311	0.3102	15	4-6

6.2.7.2 Comparison of PCATD Task Evaluations

In Johnson & Stewart II's (2005) study, six experienced flight instructors evaluated the training effectiveness of a commercial PCATD, running MSFS 2000 software. The US Army helicopter instructors ranged in age from 33 to 55 with total aircraft flight experience ranging from 1153 to 5500 hours. The demographics of the US Army flight instructors were very similar to the age range and flight experience of the ARHT helicopter pilots. All instructors were required to evaluate their PCATD in terms of how well it supported the seventy-one specific U.S. Army Finally, Krippendorff's alpha was used to measure inter-rater reliability and Initial Entry Rotary Wing (IERW) Common Core flight tasks. They were asked to provide one evaluation for each task. There were four possible levels of evaluation of suitability of the PCATD for each task and that would provide the student with the most improvement in performing that task in the aircraft. These categories of suitability were *Not at all* (0), *Slightly* (1), *Moderately* (2), and *Well* (3). The list of seventy-one tasks was reduced to fifteen tasks that matched the tasks evaluated by the ARHT pilots in the BK 117 PCATD. The ARHT evaluation had one evaluation category of missed approaches (overall) whereas the Johnson & Stewart II study was more detailed and recorded evaluations on missed approaches for each individual type of instrument approach (for example, NDB, VOR & ILS). As noted in Table 6-10, in these cases the mean rating was averaged.

Statistical analysis of the ratings was undertaken using the nonparametric Spearman rank order correlation. The results are outlined in Table 6-10 and Table 6-11. Spearman's correlation was considered the best measure to use for non-parametric, ordinal data, where N is relatively small. The comparison between the ARHT pilots and the US Army flight instructors displayed a significant positive correlation. This indicated that there was a high level of agreement between the two groups of evaluators concerning the effectiveness of their respective PCATDs for helicopter IFR/VFR training. Yet both PCATDs had significant differences in the level of the fidelity of the hardware and software. Both the ARHT pilots and the US Army pilots indicated that the PCATDs were best suited for IFR training, particularly instrument procedures. VFR training was possible on both of these devices but was less effective.

Table 6-10. ARHT Pilots Evaluation vs.US Army Instructors Evaluation

ARHT Flight Training Tasks	Mean Rating (0-4) NZ ARHT Pilots	Mean Rating (0-3) US Instructors
Instrument Scan	2.5	1.83
Airspeed Control	2.3	2.0
Altitude Control	2.6	1.83
Navaid Tracking	3.3	2.28*
Procedure Turns	3	2.0*
Holding Patterns	3	2.2*
Intercept Localiser	3.3	2.2*
Intercept Glide Slope	3.3	2.25
Missed Approach	3.2	2.28*
SID Rehearsal	3.0	2.17
STAR Rehearsal	3.3	2.28*
Navigation	3	2.0
Circuits	1.2	1.6
Overhead Rejoin	1.2	1.2
Hovering	0.8	0.33*

* = Average score of three different types of this manoeuver

Source: (Johnson & Stewart II, 2005) - "Utility of a Personal Computer-Based Aviation Training Device for Helicopter Flight Training." *International Journal of Applied Aviation Studies* **5**(2): 21.

Table 6-11. Spearman Rank Correlation -
ARHT PCATD Evaluation & US Army PCADT Evaluation

Comparison PCATD Evaluation	Spearman Rank Correlation (rs)	Number of Tasks (N)	Level of Significance
ARHT Pilots vs. US Army Instructors	0.92	15	p<.001

Source: (Johnson & Stewart II, 2005) - "Utility of a Personal Computer-Based Aviation Training Device for Helicopter Flight Training." *International Journal of Applied Aviation Studies* **5**(2): 21.

Heuristic Evaluation

When the task evaluation was completed on the ARHT PCATD, seven statements were presented to the helicopter pilots. The statements evaluated the overall fidelity of the PCATD and the user interface. For the sake of consistency, the pilots were required to respond with the same Likert scale as used in the task evaluation. The statements and responses were:

1. The physical fidelity of the MVRC flight controls are at a high enough level in terms of accuracy and feedback response to conduct effective helicopter (IFR/VFR) training.

Three pilots Moderately Disagree, one was Neutral, and two Moderately Agree.

The problem with the flight controls according to most of the pilots was the sensitivity of the flight controls, especially in the hover, and the lack of force feedback. Although the controls had no feedback, they were spring-loaded and provided some measure of tactile response. Due to the lack of force feedback, it was more difficult to hover in the PCATD than the real helicopter but after sustained practice, a few of the pilots were eventually able to achieve a consistent hover. Two comments were:

> "There was variance in flight controls and sometimes unrealistic roll and pitch. This means that pilots end up learning new simulator flying skills rather than practising aircraft skills."

> "The increased difficulty in hovering in the PCATD may be an advantage as ab-initio pilots might transition more easily to hovering tasks in the real helicopter."

Although flight control fidelity was not optimal, the MVRC flight controls (consisting of a Cyclic, Collective, Twist Throttle, & Anti-Torque Pedals) used in the ARHT PCATD had been externally validated by other users. The identical set of flight controls were installed in a number of PCATD systems developed by the manufacturer RC Simulations for commercial and military flight training (RC Simulations, 2005). The fidelity of the flight controls was an on-going issue. However, it was significantly improved with the installation of software filters and hardware modifications, to improve responsiveness, and reduce sensitivity.

2. The resolution of the NZ terrain depicted in the PCATD is accurate enough to conduct effective helicopter (IFR/VFR) training.
One pilot Moderately Disagrees, three Moderately Agree, and two pilots Strongly Agree.

The high resolution and accuracy of the terrain was achieved by the installation of detailed topography, more detailed terrain modelling, and the development of customised 3D objects. The pilots agreed that the terrain display was superior to the terrain fidelity found in most commercial FTDs being used for flight training in NZ.

3. The flight model characteristics of the BK 117 developed for the ARHT PCATD accurately match the real helicopter.
Three pilots Moderately Disagree, two were Neutral, and one Moderately Agrees.

One pilot commented that:

> “The flight simulator is very useful but requires a lot of focus to fly accurately which can detract from actual procedural training benefit. The real aircraft is more stable.”

The introduction of a menu of three different flight models (Advanced, IFR, and VFR) provided more stability and flexibility in the flight model for training purposes but the pilots indicated that there was still a need for further improvement.

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to conduct effective helicopter (IFR/VFR) training.
One pilot Strongly Disagrees, one Moderately Disagrees, three were Neutral, and one Moderately Agrees

Two main limitations of the PCATD were the field of view (FOV), and the depth of field. One data projector was used in the PCATD and it was able to display an FOV of 90 degrees. Peripheral visual cues are required for hovering, traffic pattern flight, overhead rejoin, autorotation, and other VFR tasks. Helicopter pilots use out-the-window visual cues to calculate the height above terrain and rates of descent for a range of VFR tasks such as hovering, landing approach, and autorotation. Although one study indicated that 90 degrees should be adequate for VFR training (Comstock, Jones, & Pope, 2003) one ARHT helicopter pilot stated, "visuals need to be 120 degrees FOV or more". The adoption of the China Hat design feature in the ARHT PCATD, as described in Proctor, Panko M, & Donovan (2004) was used by the helicopter pilots to provide a 360-degree snapshot FOV. However, they found it quite disorientating and were less enthusiatic about using this feature.

5. The instrument panel depicted in the PCATD is realistic enough to conduct effective helicopter (IFR/VFR) training.

Three pilots Moderately Disagree, one was Neutral, and two Moderately Agree.

Two relevant comments were made in the open question:

> "Key instruments need to be very realistic (GPS, HSI, EFIS). Other instruments such as radios do not need exact fidelity."

> "As an IFR procedural trainer it is good, but the cockpit ergonomics need to resemble the actual BK 117 more."

6. The TracMap training interface in the PCATD is realistic enough to replace TracMap training in the helicopter?

Five pilots Moderately Agree and one pilot was unable to rate it.

The use of the TracMap GPS Search & Rescue System that was interfaced with the ARHT PCATD was a successful enhancement to the overall project. Most of the pilots stated that it was very useful to train with the unit in real time in the PCATD, outside of the helicopter. There was also a considerable economic benefit to the rescue service to conduct all preliminary training of the GPS unit in the PCATD.

7. What other issues concerning the PCATD did you notice while performing the evaluation (Problems, concerns, improvements, limitations, etc.)?
No other issues were raised by the evaluators.

6.2.8 NZ Civil Aviation (CAANZ) Certification of the ARHT PCATD

Apart from general IFR/VFR helicopter training, an additional aim of the Stage 2 Project was to develop the ARHT PCATD to a level of fidelity that would achieve FSD2 Synthetic Flight Trainer certification (CASA, 2006). CAANZ certification with its emphasis on aviation safety also provides an internationally recognised validation of the overall fidelity, engineering quality, and measure of training effectiveness of the PCATD (see Appendix G1). Certification can also strongly influence future commercial development as many flight training schools are interested in PCATDs that can not only provide IFR/VFR procedural training but also allow training time to be logged towards instrument ratings (CAA, 2006). A comparison of the economic benefits of using the PCATD at ARHT is outlined in Table 6-12:

Table 6-12. Cost Comparison of Operating Helicopter vs. PCATD

Cost of Aircraft Operation	Cost of PCATD Operation
Helipro Aviation Training NZ Robinson R22 & Robinson R44 Cost $300 - $600 per hour	Elite AT-21 PCATD Cost $NZ130 per hour (Drayton, 2012)
ARHT ` Kawasaki BK 117 Cost $2000 - $3000 (dependent on tasking)	SR3 Kawasaki BK 117 PCATD Cost $NZ70 per hour (Walley, 2012)

Two general aviation flight simulator SMEs who are employed by CAANZ conduct all flight simulator certification and flight simulator audits in NZ. An application was lodged with them in 2010 to seek CAANZ IFR/VFR certification for the ARHT PCATD. They travelled to the rescue service soon after and conducted a full days certification audit on the ARHT PCATD and all relevant training documentation (Parker, 2011). The PCATD audit checklist, which was quite extensive, is outlined in Appendix I. It includes assessment of the PCATD's physical structure, instrument systems, radio navigation systems, operating characteristics, instructor station, pilot station, handling characteristics, and documentation. The ARHT PCATD was certified for all of the above criteria (see Section 2.2.4), which made it of significant training and economic value to the helicopter rescue service. Other criteria that had to be met for certification included:

1. A regular maintenance schedule with a recording system for defects;
2. Flight instructor SFT authorisations;
3. Flight examiner authorisations;
4. A SFT training syllabus;
5. A SFT Standard Operation Procedures Manual;
6. Emergencies Procedures Manual.

After a series of minor modifications to the ARHT PCATD, NZ CAA certification was achieved on 29 September 2010 (CAANZ ARHT, 2010) (see Appendix G1,G2).

6.2.9 Discussion

This study was an evaluation of the PCATD used for helicopter IFR/VFR training at an operational helicopter rescue service. The rescue service required a PCATD to assist with IFR ratings assessment, instrument currency training, and VFR training. The evaluation was in two parts. The first part was a behavioural evaluation (cognitive walkthrough) here he pilots performed a flight task at least once before providing a rating. The second part was a heuristic evaluation of the PCATD's fidelity and user interface. The sample of pilots who performed the evaluations represented the operational aircrew that would have exclusive use of the PCATD for training purposes.

6.2.9.1 Task Evaluations

In terms of the task evaluations the helicopter pilots' assessments did agreed with other research that indicated high levels of fidelity might not be necessary for successful task transfer (Alexander, et al., 2005; Macchiarella, et al., 2006; Taylor, et al., 1999). Most of the pilots expressed positive remarks about the usefulness of the PCATD for IFR task training. However, for VFR training they required more improvements in the overall fidelity of the PCATD. While performing the task evaluations they were able to complete all the designated IFR or VFR tasks.

Nevertheless, completing VFR training tasks required them to focus more, and expend more effort in manipulating the flight controls to fly accurately. Feedback from pilots had indicated that the level of concentration required to fly the PCATD was greater than that required to fly the real helicopter, to achieve the same outcomes. When using the PCATD for VFR training, the pilots had to adapt to limitations in flight control fidelity and develop techniques to compensate for issues such as flight control sensitivity. One of the senior pilots indicated that this might not necessarily be a disadvantage. In the long term, overlearning might lead to improvements in a pilot's fine psychomotor control, and consequently less difficulty in controlling the real aircraft.

6.2.9.2 Heuristic Evaluation

In the heuristic evaluation, the helicopter pilots still expressed a partiality for high levels of fidelity and realistic instrument panels. Although the PCATD's design was focused on cost effective ways of improving functional fidelity, the helicopter pilots still expressed a traditional preference for high levels of face fidelity. Many of the helicopter pilots had indicated in the evaluation form that they had completed some training in high fidelity fixed wing FTDs and so they acknowledged that they exhibited some bias towards high fidelity simulation.

This preference for high fidelity is supported by other studies, which have confirmed that expert pilots require high levels of fidelity and difficult tasks to enhance their transfer of learning (Alessi, 1988; Stewart II., et al., 2008). Therefore, interface designers, cognitive engineers, and other aviation experts must weigh the state and training level of the learner when determining the extent of fidelity to programme into flight simulation devices (Flach, Hancock, Caird, & Vicente, 1995).

The ARHT PCATD had a visual display screen that was much larger than the other PCATD visual displays discussed in the literature review. This enabled the ARHT PCATD to display a field of view of 90 degrees which one study indicated should provide sufficient visual cues for effective VFR training (Comstock, et al., 2003). The ARHT pilots disputed this, and found the lack of peripheral vision in the visual display, restricted their ability to fly the advanced VFR exercises accurately.

6.3 Stage 3: Development of the SAV1 PCATD for VFR Procedures Training

6.3.1 Introduction

In Stage 1, a PCATD was developed for fixed wing IFR/VFR flight training. The second stage involved the development of a PCATD for rotary wing VFR & IFR flight training. Neither organisation (RNZAF, ARHT) had FTDs or PCATDs in their flight-training inventory. This had created a gap in their flight-training programme but in both cases, the purchase of a commercial FTD was not possible due to limited funds. The solution to this dilemma was to develop a relatively low cost but effective PCATD to support their respective flight training programmes. In this Stage 3 development, a flight simulator designed for VFR training with high fidelity visual displays had the potential to address two specific training problems. Many of the international students studying at the University flight training school were having difficulties with successfully completing the navigation exercises in the aircraft. This was mainly due to their unfamiliarity with NZ terrain and its varied topography. NZ trainees from different regions of the country also had some difficulty with identifying local townships and landmarks while completing navigation exercises. Another training issue was the increasing requirement for remedial flight training to assist pilot trainees who were having difficulty with completing general VFR training exercises in the aircraft. These included basic exercises such as climbing and descending, and advanced exercises such as landing approaches and landing flare (F. Sharp, personal communication, 30 April 2008).

The development of customised terrain in Stage 1 and the development of visual display technology in Stage 2 would enable the two technologies to be integrated into the Stage 3 development. In this stage, because of the gap in the VFR flight-training regime, and to reduce remedial training flights in the aircraft, there was a requirement to develop a PCATD to assist trainee pilots primarily with cross country VFR navigation rehearsal and remedial VFR training. At the time, the flight training school used FRASCA FTDs to assist with its flight-training programme. Because of the economic benefits afforded by the Frasca FTDs for instrument training, their use for any other training purposes such as VFR training was severely restricted (Frasca, 2006a). In addition, the FTDs had little or no visual capabilities and were not particularly suited to VFR training requirements. All of these training issues and constraints would provide the necessary impetus for the accelerated development of a PCATD that would be suitable for VFR flight training.

6.3.2 Background

The university aviation school outlined in this study is an educational institute that offers a professional degree for trainee pilots incorporating flight training (fixed wing only) with academic studies. Students graduate with a university degree in aviation, a Commercial Pilot's Licence, multi-engine instrument rating, and Air Transport Pilot licence theory credits (NZTE, 2010). Prior to 2009, the training aircraft inventory included Cessna 172, Piper Cherokee, Seneca's (Twin-engine) and other aircraft leased for specific requirements (e.g., Robin 2160 for aerobatics). Initially the school operated two flight training schools but in 2007, there was an organisational restructure and all flight systems training and academic activities were relocated to a single base.

6.3.3 Literature Review

PCATDs have been proven to be effective devices for IFR training (Talleur, et al., 2003) but they also have the potential to be used for VFR Navigation and remedial VFR training (Williams, et al., 1996). Studies seem to indicate that if the PCATD's terrain detail is depicted at a high resolution, and the visual display technology can display a wide FOV, then the device should provide an accurate simulation platform for cross country navigation exercises. Also pilots could use this type of customised VFR PCATD to rehearse departure procedures, enroute procedures, and arrival procedures.

6.3.3.1 Using PCATDs for VFR Navigation Rehearsal Training

The most cost effective and practical method of overcoming unfamiliarity with flight training terrain is through flight simulation. A suitable PCATD or FTD makes it possible to prepare for a navigation training flight through unfamiliar terrain by rehearsing the flight as accurately as the visual fidelity of the simulator will allow. The normal procedure for a navigation training exercise is to use maps and other briefing materials. However, maps are a simplified representation of the actual terrain and require the student to relate the scale from the map to the real world, a difficult cognitive task with a high possibly of error. The advantage of flight simulation is that computer generated depiction of terrain can more accurately represent size differences and spatial relationships between geographical features (Williams, et al., 1996).

A number of studies have indicated a positive transfer of training where PCATDs with medium to high visual fidelity have been used for VFR navigation rehearsal. Williams et al (1996) found that active rehearsal is superior to passive viewing for training transfer. Also, the study stated that a high level of scenery detail may not be required, and this is supported by other research (Lintern, et al., 1997). However, flight instructors at the school insisted that high levels of detailed scenery provide more visual fidelity and therefore better training transfer.

Similarly, Bone & Lintern (1999) tested whether rehearsal in a PCATD could enhance a pilot's preparation for navigation through unfamiliar terrain. They devised an experiment to assess the differences between rehearsal (with and without guidance) using a PCATD, and map study. In this case, guided rehearsal consisted of a computer generated route line to assist the trainee. The navigation exercise was completed on a PCATD that included a joystick, a helicopter flight model, and a dedicated graphics workstation PC that could generate high and low fidelity terrain. Flight instrumentation was displayed on a 16-inch colour monitor and the visual scenery was projected onto a large display of two screens each measuring 228.6 cm (7 ft.) x 304.8 cm (10 ft.). Following a rehearsal or map study phase, participants were required to navigate through an environment and point to objects within the navigational database but out of sight. To ensure that all participants were faced with a transfer task, the visual fidelity of the test task was enhanced in relation to the rehearsal task. A route-following test of navigation knowledge in the PCATD demonstrated that unguided rehearsal was better than map study or guided rehearsal for the development of route knowledge.[21] In addition, a pointing task revealed that unguided mission rehearsal was as good as map study for the development of survey knowledge.[22] Bone & Lintern (1999) found that unguided rehearsal in a flight simulator was superior to map study and guided rehearsal for developing the critical skills of route and survey knowledge. Once again, this study reinforced the use of PCATDs and their superiority for VFR navigation rehearsal instead of map study. Unguided rehearsal was better than guided rehearsal as it required the pilot to pay attention more to all the visual terrain cues displayed rather than just following a line on the screen. Both of these studies support the use of PCATDs for navigation rehearsal and indicate that they provide better training outcomes than traditional methods such as map study. Most PCATDs have display systems that cannot match the visual fidelity of full flight simulators. Therefore, achieving the level of scene detail required for effective navigation rehearsal would be an issue that would have to be determined during the Stage 3 PCATD development and subsequent evaluation.

Technological issues related to PCATD visual displays such as field of view (FOV), display resolution and terrain resolution would have to be resolved also. The main training objectives in the development of this PCATD was cross-country navigation training, remedial VFR training, and to provide the students with an opportunity to practice VFR procedures without incurring the extra costs of aircraft or FTD training time[23].

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[21] Route knowledge involves understanding how to proceed from point to point by following a set of procedures and is characterised by appreciation of sequential locations without appreciation of global relationships (Hirtle & Hudson, 1991)

[22] Survey knowledge is the map-like understanding that supports generalization beyond learned routes and permits one to locate objects within a global frame of reference (Hirtle & Hudson, 1991)

[23] The intention was not to seek CAANZ certification for this PCATD as that applies mainly to IFR criteria (CAANZ, 2011a) The current CAA regulations do not allow pilot trainees to credit VFR training time on the PCATD in their log book. However his may change in the future.

Another advantage of this type of PCATD (with flight recording capability) was that it could be used with instructor authorisation for individual practice but training need not necessarily have to be supervised by a flight instructor.

6.3.3.2 Using Multi Screen Displays in PCATDs for Effective VFR Flight Training

There are some fundamental differences between IFR and VFR flying which have a strong influence on the design of PCATDs. Because of the nature of IFR flying, PCATDs and FTDs used exclusively for IFR flight training do not actually require visual displays and for many years, they did not (Frasca, 2011a). In fact, the visual displays can be a distraction to the student when performing critical instrument scans. Flying by instruments means controlling the aircraft and maintaining proper attitude in the total absence of visual cues (FAA, 2012b). Instrument flight training involves pilot trainees using flight and navigation instruments as the primary references to maintain control of an aircraft's attitude, altitude, and direction.

Advanced instrument flight training involves the use of radio navigation instruments along with flight instruments. Basic instrument flight tasks include standard rate turns, climbing and descending turns, and holding patterns. Advanced instrument flight tasks include ILS approaches, VOR tracking, and IFR route navigation (FAA, 2012b). Primary flight training tasks are referred to as VFR or visual flight rules tasks. Successful completion of these tasks in an aircraft or simulator requires the pilot trainee to use out-of–the-cockpit views and ground-horizon references to execute the required aircraft manoeuvres. Because of the nature of VFR flying, PCATDs and FTDs used for VFR flight training place more emphasis on out-of-the-cockpit visual displays and conversely flight instrument panels could be simplified with basic six pack displays of flight instruments (Roessingh, 2005).

Examples of VFR tasks include stalling practice, steep turns, take-off, and landing, overhead circuit rejoins, and cross country navigation. Advanced VFR tasks include forced landings practice, advanced circuits, low flying, and aerobatics (FAA, 2012c). The limited field of view issue outlined in this study was the same issue that had arisen in Stage 1 and 2. Single screen displays were not providing enough visual fidelity to allow pilot trainees to rehearse the full range of VFR tasks. This finding was supported by studies on the fidelity of PC-based simulators (Alexander, et al., 2005).

Khan, Rossi, Heath, Ali, & Ward. (2006) would provide some supporting evidence for the use of multi-screen displays in PCATDs. In their study, they examined the effects of using out-of-the-window visual cues for training fixed wing ab-initio pilots to fly two different VFR manoeuvres. Four PCs were networked together and three out-of-the-window (OTW) views were driven by three PCs while the fourth computer displayed the instrument panel.

The software used on the PCATD was MSFS 2002. Flight data was recorded for later analysis. The flights were flown in VFR conditions and the simulated aircraft was trimmed for straight and level flight. Visual cues for both experiments consisted of visual hoops on the flight paths through which the pilot was required to fly if proper parameters were maintained. After sufficient training, participants completed a similar but more challenging task with no visual cues. The first study compared the use of visual cues vs. no visual cues for training a straight-in-landing approach.

The second experiment examined the use of visual cues as well as the density of visual cues in training a level 360^{o} turn. Participants learned to a fly a 360^{o} level turn with a bank angle of 10^{o} at a constant speed of 75 knots under VFR conditions in a Cessna 172. The results indicated that visual hoops did not significantly improve performance on the landing task. This may be due to participants primarily focusing on the runway as a main OTW cue as well as scanning flight instruments. In this experiment, the visual hoops may have been an unwelcome distraction. In the second experiment, the visual hoops seemed to provide some training value in learning to fly a 360^{o} level turn. Interestingly in the second experiment, a lower number of hoops provided better training value (less flight manoeuvre errors) than a higher number of hoops. This was probably due to the increase in the variable time between hoops that gave the participant more time to scan the flight instruments before switching back to the OTW. The main implication of this study was that multi-monitor visual displays provided an increased FOV. The increased FOV enabled the participants to complete the various VFR manoeuvres successfully, react correctly to the various visual cues projected on the multi-screen display, and fly the aircraft accurately within certain altitude, and speed parameters.

6.3.3.3 PCATD Visual Display (FOV) and its Importance for VFR Flight Training

The main question that arose when designing the Stage 3 PCATD was whether increasing the FOV of the display system would increase its effectiveness for VFR training. Several studies had supported the importance of FOV in a PCATD's visual display and the optimum FOV beyond which there is no discernible training benefit (Comstock, et al., 2003; Keller, et al., 2003). Also, it is essential in simulation design to take into consideration the limits of the human visual system. It would be counter-productive and costly to increase the FOV and the resolution of a simulators visual system beyond the visual capabilities of the average pilot. The FOV of a pilot's visual field is approximately 180 degrees in the horizontal plane and 130 degrees in the vertical plane. Approximately 140 degrees of the horizontal FOV plane is shared by both eyes. This is a particularly wide field of view in terms of simulation and is further enhanced by head and eye movements. To develop a PCATD with a visual field of this size, and a resolution to match the human eye, would be extraordinarily complex and expensive.

Fortunately, the eye does not have the same resolving power across the whole FOV. The pilot's visual FOV beyond 10 degrees from the centre of the eye is poor at object recognition although it can still detect motion. This means that high-resolution objects do not need to be generated all of the time throughout the whole visual field. Because of the eye's limitations, compromises in the resolution of image generation can then be made (Lee, 2005). The level of FOV in relation to VFR flight training performance was investigated in a study by Comstock Jones and Popel (2003). Controlling an aircraft by reference to out-of-the-cockpit views is a necessity in VFR training and therefore the requirements are more stringent. Information from the visual external scene (Display FOV) provides vital cues for aircraft altitude control, especially in the pitch and roll axes.

Most PCATDs have an FOV range between 30-75 degrees horizontal (FOV_H). In this study, a method was devised to vary the FOV_H of a computer-generated artificial horizon and measure how this affected attitude (roll and pitch) control. Improvements in roll control correlated with increases in FOV_H up to 110 degrees. The implications of this study was that FOV_H display systems must measure at least 110 degrees horizontal to provide the full roll control cues necessary for a pilot to successfully complete VFR manoeuvres.

6.3.3.4 PCATD Visual Display (Detail & Resolution) and its Importance for VFR Flight Training

Alongside field of view, another component that affects simulation display is object detail, which is closely related to display resolution. A simulator scene generator may be capable of providing a very high level of object detail but unless the display system has sufficiently high resolution, it cannot display it. The higher the visual image resolution of the PCATD, the higher the object detail it can display. For successful VFR navigation rehearsal, discrimination and identification of ground-based objects is critical. Objects such as roads, lakes, rivers, buildings and other features need to be matched to aeronautical maps and charts to identify VFR reporting points, waypoints, and controlled airspace boundaries. Increased object detail in terrain simulation is essential when a simulated aircraft operates at altitudes at less than a thousand feet above ground level. At these heights, ground reference cues are required to assist in the judgment of height, rate of altitude change, and the angle that an aircraft is approaching the ground. The size-distance relationship of objects is an critical visual cue for the interpretation of altitude, closing distance to another aircraft, rate of change in altitude and landing approaches (Lee, 2005).

Keller, Schnell, Lemos, Glaab, & Parrish (2003) compared pilot performance and workload and its relationship to display resolution. Although a high-resolution display is desirable for increased image fidelity, it may be very expensive to achieve. In addition, there may be a marginal rate of return in terms of workload, pilot performance, and situation awareness. Thirty-four pilots flew sixteen approaches to an airport in a flight simulator using a Cessna 172 flight model. During these approaches, the pilots' flight performance was recorded to determine the effect of display resolution and field of view on flight performance. In the experiment, the options included display resolutions of 80, 90, 105, and 120 pixels per inch and FOV values of 22°, 30°, 60°, and 90°. Four flight performance variables were measured: Lateral Deviation, Vertical Track Error, Runway Alignment Error, and Directional Input.

The results of this study and the recommendations made by the authors were as follows:

1. Performance increased as display resolution increased but levelled off at 105 pixels per inch when flying VFR manoeuvres with sole reference to terrain.
2. An FOV of 60°-90° was best for advanced navigation tasks but only 60° was required for straight in approaches to the runway. For tasks that require turning manoeuvres (i.e. most VFR tasks) the highest FOV possible is appropriate.

6.3.3.5 PCATD Visual Display (Texture) & Its Importance for VFR Flight Training

The importance of FOV, and display resolution have already been discussed but texture and colour generation are essential in flight simulation image-generation as well. A texture gradient changes the density of texture elements as a function of distance from the viewer. This provides further cues to depth and distance of objects in the visual fields. Texture can also provide additional cues about height above ground, sloping terrain and rate of descent as close to the ground (Lee, 2005).

A study by Mulder, Pleisjant, van der Vaart, and Wieringen (2000) examined how the level of pictorial detail affected the timing of the landing flare in an aircraft, which is a good example of an advanced VFR task. An objective of this study was to determine whether performance was influenced by the addition of ground texture to the airport runway. Ground texture was defined as a spatial array of patches, lines, or points varying in size, shape, posture, colour, or brightness. The visual display was generated on a Silicon Graphics seventeen- inch monitor and examples of the different runway scenes are outlined in Fig. 6-9.

The results indicated that improved performance could be due to the presence of ground texture in the display improving the perception of time–to–contact (TTC). Where TTC is defined as the time remaining to the moment that the wheels make contact with the runway if no pilot action is taken. The design of the Stage 3 PCATD would place a strong emphasis on terrain resolution and 3D object display, which would assist students with advanced VFR tasks such as approach & landing, forced landing practice, and circuits.

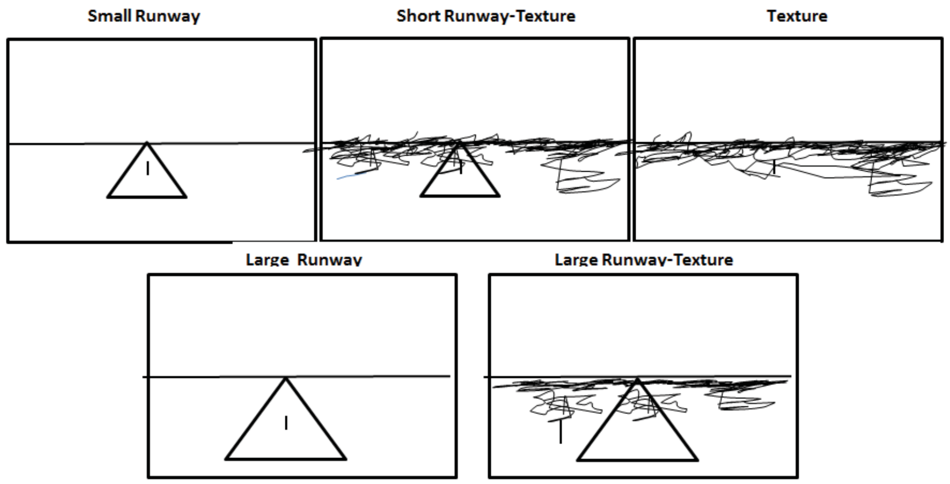


Figure 6-9. Synthetic Runway Scenes (Facsimile)

Source: (Mulder, et al., 2000, Fig.8) - The Effects of Pictorial Detail on the Timing of the Landing Flare: Results of a Visual Simulation Experiment. *The International Journal of Aviation Psychology, 10*(3), 291-315.

Summary

Several studies have been discussed that have supported the use of PCATDs for VFR navigation rehearsal over traditional methods such as map study (Bone & Lintern, 1999; Williams, et al., 1996)**.** Other VFR procedures such as landing and landing flare can be very difficult to master in the air and a PCATD could be a cost effective and safe method used by the flight instructors to teach correct techniques and correct faults (Pete, 2004). Object detail, display resolution and terrain texture display are key factors that have been investigated in relation to visual displays (Harvey, 2004). When a PCATD is designed and then developed, these factors must be taken into account if it is to be used successfully for VFR flight training.

6.3.4 The Development of a VFR Procedural Trainer PCATD

The Stage 3 PCATD was specifically designed for navigation rehearsal training and remedial VFR skills training. For the VFR training role the emphasis was placed on improving the PCATD's visual fidelity by expanding the field of view (FOV), using high fidelity controls and instruments, and increasing the terrain resolution. The design incorporated many commercial off the shelf products and this reduced development and maintenance costs (see Fig. 6.10).

Figure 6-10. Stage 3 SAV1 PCATD VFR Trainer & Instructor Station

Soon after its completion, the Massey Aviation Flight School provided additional funding for a second PCATD to be developed. These low cost PCATDs were designed with a number of innovative features. These included multi-screen displays, enhanced visual resolution and terrain detail, commercial off the shelf (COTS) flight controls and avionics with improved fidelity, and low cost but versatile flight simulation software. A major enhancement implemented in Stage 3 was the use of multi-screen displays. The PCATDs described in Stages 1 & 2, had used only single screen displays with a limited field of view. At the time of this development, multi-screen visual displays were only used in full flight simulators and high fidelity FTDs due to the high cost and complexity of the technology (Frasca, 2007; Pacific Simulators, 2012). Because of this technological barrier, many commercial PCATD s and FTDs used in flight schools in NZ and overseas were restricted to either no visual displays or single screen displays only (Elite, 2010; Frasca, 2006a, 2011a; Pacific Simulators, 2012). Single screen displays have a limited field of view which restricts their use for VFR training, a problem noted in a number of studies on the use of PCATDs for training (Koonce & Bramble, 1998; Macchiarella, et al., 2006; McDermott, 2005a). However, the development of this technology at a relatively low cost was a significant challenge, Full flight simulators use powerful graphic workstations which can easily split the display into multiple channels (Barco Simulation, 2011). Low cost multi-screen displays require the exact synchronisation of networked computers and monitors to display the output of a central computer (Lambda Vision, 2011).

A technique that involves considerable modification of the software interface to ensure stability. The hardware configuration of this PCATD also had to be combined with flight simulation software that was not inherently designed to work with this networked configuration.

In Stage 2, the helicopter PCATD had been designed with a single out-of-the-cockpit view but with three separate monitor views for the instrument panel displays. The development of this hybrid display had provided indications as to how the more difficult task of creating multiple out-of-the-cockpit views might be achieved. This would be the first time that this type of low cost multi-screen technology would be used in a PCATD for VFR pilot training in NZ. The use of three synchronised 19” monitors on the Stage 3 PCATD to display scenery coupled with the MSFS software visual display magnification feature had increased the field of view to 120 degrees. In addition, two additional 19” monitors were used specifically for the instrument panel display. This instrument panel multi-screen display was an extension of the technology that had been used successfully in the Stage 2 project.

The availability and relatively low cost of PC compatible graphic accelerator cards have made them a popular choice for driving high-resolution visual display systems. Dedicated graphic accelerator cards installed into the Stage 3 PCATD provided high-resolution 3D object rendering with 32-bit colour generation (16 million colours) and new shader technology (Nvidia, 2010).This graphic capability enabled displays of high-resolution terrain imagery and 3D objects that would duplicate real world terrain to a horizontal accuracy of 20 metres and 10 metres vertically (Stelmack, 2005). The use of this technology would achieve the necessary requirements to display terrain features to a high level of accuracy suitable for VFR navigation training. The graphic display capability of the Stage 3 PCATD despite it being low cost ($6000) had a technological advantage over most commercial FTDs being used in flight training schools at the time. Legacy FTDs could not match the high fidelity terrain and detail of the visual system installed in the SAV1 PCATD (Frasca, 2006a) . Several studies support the argument that higher resolution displays can provide an advantage in VFR training transfer performance (Keller, et al., 2003).

In 2003, a U.S. company Precision Flight Inc. began manufacturing stand-alone flight controls for PCATDs. These dual flight controls were designed with metal components and high tension springs. They consisted of two fiberglass yokes, a central throttle quadrant and twin aluminium cast rudder pedals. A crucial design feature was the use of precision linear potentiometers that provide an accurate range of control movement. These new all-metal flight controls provided relatively high levels of flight control fidelity, robustness, and accuracy of response (PFC, 2012). Compared to the joysticks used in Stage1 and the modified joystick flight controls used in Stage 2, the PFC flight control fidelity was superior, especially in response rate. The flight- control response rate is a critical factor in determining the level of flight control fidelity required for VFR flight training (Williams, 2006). The flight controls also included custom switches for Flaps, Landing Gear, and Elevator Trim.

Coupled with custom navigation instruments and radio modules the functional fidelity of the SAV1 PCATD had been enhanced to a level that was comparable to the certified FTDs in the flight schools inventory. Most FTD manufacturers produce all their own proprietary hardware and software components. This means flight schools require a high capital outlay to buy or lease FTDs as well as being locked into long term maintenance contracts (Frasca, 2007). The Stage 3 PCATD was designed to integrate COTS hardware and software components sourced from different manufacturers based on flexibility and low cost. Nevertheless, this method requires expertise in developing or modifying software interfaces between different components to ensure they communicate with each other correctly. A database of these software interface programs was created in Stage 3 and they were replicated, modified, and updated for subsequent stages of PCATD development. This type of approach had been used by PC hobbyists and gamers but there were doubts as to whether it was stable enough for commercial flight simulation development(Alexander, et al., 2005). The key is to have an intensive software-testing regime, and well-documented stages of development. Also close links need to be established with all the various component suppliers and their technical support staff. It would take several years and pressure from rising costs in aviation training before this low cost developmental approach would become relatively commonplace aviation simulator design (KiwiFlyer, 2012).

The fourth feature of the PCATD design was the use of MSFS software. This software had been used in Stages 1 & 2 and this ensured continuity in software development and kept maintenance costs low. The majority of FTDs operating in flight training schools in NZ were using proprietary software and little or no modification of the software was possible on these devices. Ownership of these proprietary devices meant total dependence on the manufacturer for innovation or improvements in design (Frasca, 2012a)

The use of MSFS for the Stage 3 SAV1 PCATD provided access to an extensive database of detailed scenery, flight models, and software tool kits. This database had been developed over the last decade by the flight simulation community and suitable modules could be easily incorporated into the software design (Martin, 2010). In addition, the experience gained by developing MSFS flight models for Stages 1 & 2 meant that the development of an accurate and realistic Piper Cherokee flight model for this project was achieved within a very short time period. This type of software development structure (MSFS 2004 SDK, 2012) meant that the implementation of software changes or improvements, that might be suggested by the flight instructors and pilot trainees could be achieved in a timely fashion.

6.3.5 Evaluation of the Stage 3 SAV1 PCATD

The evaluation of the PCATD was driven by the two primary objectives. Could the PCATD be used effectively for: VFR navigation rehearsal and remedial VFR training? An evaluation of the SAV1 PCATD was undertaken by five flight instructors at the university training school. The purpose of this evaluation was to determine whether the PCATD could be used effectively for VFR navigation rehearsal and remedial VFR training before it was formally accepted into the flight-training programme for students.

6.3.5.1 Participants

At the time of the development of the PCATD, the aviation school had approximately 20 active flight instructors located in each of the two flight centres (five senior flight instructors were recruited for the evaluation process). There were approximately 180 active pilot trainees at the school in various stages of training. The demographic composition of the five flight instructors undertaking the evaluation was as follows:

1. The instructors were male;
2. The instructors ages ranged from 25-45;
3. The total aircraft flight hours of each instructor ranged from 500-2400 hours with a mean of 1540 hours (Median 2000 hours);
4. Each instructor had more than three hundred hours of flight instructional experience;
5. The instructors had extensive flight experience on the Piper Cherokee, the aircraft being simulated by the PCATDs;
6. The instructors had senior training roles and supervisory roles in the training school.

6.3.5.2 PCATD IFR/VFR Evaluation by Flight Instructors

The flight instructors were selected on their level of seniority and flight experience. The evaluation of the PCATD took place over the period of a month and involved flight instructors from both flight centres. All of the flight instructors had significant experience on training and testing students on the Frasca FTDs, which were part of the training inventory of the flight school. The instructors had very little experience with using PCATDs. However, a few were familiar with MSFS software and had used it on an informal basis. Although it was a small number of experienced instructors performing the evaluation, Miller and Jeffries (1992) found that as the relative expertise of evaluators increases, the fewer the number of SMEs are required for the evaluation.

6.3.5.3 Cognitive Walkthrough (Task Evaluation)

Initially the flight instructors were briefed on the operation of the PCATD and any limitations that the device had. In the first phase, the flight instructors practiced three basic VFR tasks, and then three advanced VFR tasks on the PCATD. They would complete these tasks in accordance with the training standards and procedures outlined in the CAA Part 61- Private Pilot Licence Advisory Circular (CAANZ, 2011e) They were allocated a set time period of up to 30 minutes to assess each manoeuvre. Each manoeuvre commenced at a fixed height and speed in the PCATD. From this point, the flight instructors practiced the VFR manoeuvre. After completing the manoeuvre to their satisfaction, they could combine with other manoeuvres in any sequence to assist them with the overall evaluation. The flight instructors were required to complete a cognitive walkthrough by practicing six different VFR tasks in the PCATD:

1. Instrument Scan (VFR). This task involved visually scanning the instrument panel in a set pattern;
2. Airspeed Control (VFR). This task involved setting and maintaining correct airspeeds;
3. Altitude Control (VFR). This task involved setting and maintaining correct altitude;
4. Navigation Rehearsal. This task involved completing a cross country navigation exercise.
5. Circuits (with Take-off & Landings). This task involved completing basic circuits including take-offs and landing
6. Overhead Rejoin (VFR). This task involved completing a standard overhead rejoin procedure in a helicopter;

At the end of each of the six assessments of the VFR tasks, the flight instructors and pilots had to rate the following statement using a Likert scale:

Practicing this particular VFR flight procedure or manoeuvre in the PCATD can improve proficiency in the aircraft.

A Likert scale was used that provided a range of responses that measured the respondent’s intensity of feeling concerning the statement. A decision was made to make it a five point scale which was influenced by previous studies (Johnson & Stewart II, 2005; Stewart, 2001). The response/evaluation categories were *Strongly Disagree* - rated 0, *Moderately Disagree* - rated 1, *Neutral* – rated 2, *Moderately Agree* - rated 3, *Strongly Agree* - rated 4. One non-scoring category was included, *Unable to Rate* - where the evaluator had not reached a sufficient level of expertise to rate the task or was unavailable.

6.3.5.4 Heuristic Evaluation

The task evaluation was followed by a heuristic evaluation where the participants had to evaluate five statements that related more to the user interface and level of fidelity of the

PCATD. The sixth statement was open-ended where they could express any concerns or suggestions about the PCATD and how the design could be improved. For the sake of consistency, the flight instructors were required to respond with similar Likert responses as the task evaluations (e.g., *Strongly Disagree, Moderately Disagree, Neutral, Moderately Agree, and Strongly Agree*). The statements used were very similar to the heuristic evaluation statements used in Stage 1 and Stage 2 (see Section 6.1.8).

6.3.6 Results

The results below are presented in three parts. First the results from the cognitive walkthrough evaluations of the PCATD, then the heuristic evaluations of the user interface and fidelity, followed by a brief description of the comments made by instructors as they evaluated the PCATD.

6.3.6.1 Task Evaluation

The results indicate that the flight instructors' task analysis of the effectiveness of the PCATD indicated a moderate agreement with its use for training the three basic VFR tasks. The three advanced VFR tasks, with mean responses being Neutral or Moderately Disagree, indicated that there were some issues with the advanced VFR task fidelity of the PCATD (see Table 6-13). The responses to the questions in the heuristic evaluation provided some insight into underlying causes for these ratings, such as the low fidelity of the terrain display resolution.

Table 6-13. Ratings for Practical Evaluation of VFR Tasks

VFR Flight Tasks (Basic & Advanced)	No. of Participants	Mean (0-4)	Standard Deviation
Instrument Scan –Basic	5	3.0	1.00
Airspeed Control –Basic	5	3.0	1.22
Altitude Control –Basic	5	2.6	0.55
Navigation Rehearsal – Adv	4	1.8	0.50
Circuits (with T/O & Landings) Adv	5	2.2	0.45
Overhead Rejoin – Adv	5	2.2	0.45

Finally, Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha coefficient was calculated for inter rater reliability, and reliability of coding. Krippendorff can also adjust for missing ratings, which was the case here. The value of α = 0.1496 indicates there was a small level of agreement between participants see Table 6-14). This result may have been due to incomplete data and the small number of raters.

Table 6-14. Stage 3 PCATD Krippendorff's Alpha Coefficient (95% Confidence Interval)

	Alpha	LL95%CI	UL95%CI	Tasks	Raters
Ordinal	0.1496	-0.1639	0.4366	6	4-5

6.3.6.2 Heuristic Evaluation

Six statements (one was open) were presented to the flight instructors as part of the heuristic evaluation. They relate to the evaluation of the user interface and fidelity of the PCATD. The Likert responses were as follows:

1. The physical fidelity of the flight controls is at a high enough level in terms of accuracy and feedback response to conduct cross-country navigation VFR rehearsal and VFR remedial exercises effectively?

One pilot was Neutral, two Moderately Agree, and two Strongly Agree.

Two criticisms of the flight controls articulated by most of the evaluators were the sensitivity of the flight controls and the lack of force feedback. The fidelity of the PFC flight controls (Yoke, Throttle, Rudder, Pedals) used in the SAV1 PCATD had already been externally validated. The identical set of flight controls were installed in a number of PCATD systems developed by Precision Flight Controls Inc. These FAA Approved Basic Aviation Devices (BATD) include the CATII BATD, CATIII BATD, and the CATII ProPanel BATD (PFC, 2004). The FAA has a mandatory requirement that PCATD flight controls have a similar response time and have a similar effect as the aircraft flight controls (FAA, 2008). The FAA certification applies to instrument flight-training requirements but indicate that the flight controls fidelity is at a high level. Instrument flight training requirements generally require more precision (e.g. procedural turns & intercept glideslope) when using the flight controls than visual flight training tasks.

2. The resolution of NZ terrain and runways depicted in the PCATD is accurate enough to conduct cross country navigation VFR rehearsal and VFR remedial exercises effectively?

One pilot Strongly Disagrees, two pilots Moderately Disagree, one was Neutral, and one Moderately Agrees.

One exercise by the flight instructors was to use a NZ Visual Navigation Map (see Fig. 6-11) and try to match geographic landmarks in the visual database (see Fig. 6-12) while performing route navigation on the PCATD. The flight instructors had made a subjective assessment that the default terrain in the Stage 3 PCATD was not accurate enough, and some Visual Navigation Chart landmarks were not easily recognisable or did not exist. VFR reporting points in real world navigation can be as obscure as a small farmhouse or rural road intersection. Many of these real world 3D objects were not found in the default MSFS NZ terrain database and each object would have to be separately developed for the PCATD. The feedback from the flight instructors was that the default terrain resolution would have to be increased to provide accurate recognition of geographical features displayed in the PCATD for navigation training purposes. FS2004 software is sold with a default 1200-metre scenery resolution (LOD 5) This level of terrain resolution was selected by Microsoft to allow the program to run at a smooth visual frame rate on most standard PCs in the world (Szofran, 2006). High levels of terrain resolution slow down the visual frame rate, and therefore require more PC processing power to process the data efficiently (Zyskowski, 2010). High performance PCs are more costly and complex but are essential for integration into PCATDs that are required to provide high terrain resolution displays.

Despite the flight instructors misgivings about the limitations in the MSFS default terrain resolution a number of CAA and FAA approved PCATDs still use this scenery or IFR/VFR training without significant alteration (Pacific Simulators, 2012; Redbird, 2010). The Stage 3 PCATD design incorporated a desktop computer with a high level of processing power and a powerful graphics card (Pentium4 2.8 GHz, Geforce 7600 GT 256 MB GPU. 2GB RAM). This meant the PC had the potential to display a level of terrain resolution well above the resolution of the default scenery.

Figure 6-11. Example of Visual Chart Segment of Auckland (Facsimile)

Source: (AIPNZ, 2010)- Aeronautical Information Publication New Zealand. Retrieved from http://www.aip.net.nz/

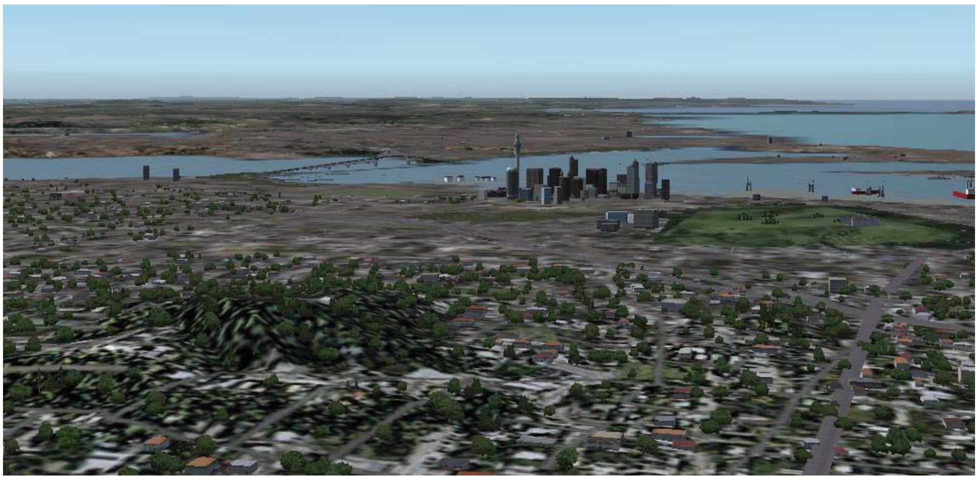


Figure 6-12. Stage 3 PCATD Screenshot Auckland NZ

Source:(Reweti, et al., 2005)- Auckland 2005 MSFS Scenery Retrieved from http://library.avsim.net/search.php?SearchTerm=reweti&CatID=root&Go=Search

3. The flight model characteristics of the Piper Cherokee developed for the SAV1 PCATD match the real training aircraft accurately?
One pilot Moderately Disagrees, two Moderately Agree, and two strongly Agree.

The only criticism from some of the evaluators was the climb and descent characteristics of the simulated aircraft were not realistic. One major difficulty was that evaluators often contradict each other (e.g. one evaluator stated the aircraft climbed too slowly and one said it was too fast). The solution was to adjust flight model parameters with a flight modelling software tool (AirED) and ensure all PCATD training sessions had pre-set aircraft configurations to ensure consistency of performance of the simulated aircraft.

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to conduct cross-country navigation VFR rehearsal and VFR remedial exercises effectively?
Two pilots Moderately Agree, and three Strongly Agree.

Most of the flight instructors agreed with the findings that a FOV of 120 degrees provided enough visual cues (especially peripheral cues) to complete the required VFR exercises. There was less enthusiasm with the use of the snapshot view function which was configured in-house. Although it could provide a 360-degree FOV, it was regarded as helpful but unrealistic.

5. The instrument panel depicted in the PCATD is realistic enough to conduct cross country navigation VFR rehearsal and VFR remedial exercises effectively?
Two pilots were Neutral, two Moderately Agree and one Strongly Agrees.

One criticism was that the analogue gauges needed to be scaled to a larger size on the screen. One flight instructor felt the instrument panel was too cluttered. Another observation by several evaluators was that the instrument panel could be simplified to a basic six-pack of essential flight information gauges, without a loss in training effectiveness. This assertion was supported by several studies (Garvey, 2006; McDermott, 2005a; Taylor, et al., 2004). The six-pack included Airspeed, Artificial Horizon, Altitude, Turn Coordinator, Directional Indicator, and a Vertical Speed Indicator. This simplified instrument display was eventually installed into the PCATD.

6. What other issues concerning the PCATD did you notice while performing the evaluation (Problems, concerns, improvements, limitations, etc.?)

The responses to the open question about any other PCATD issues were wide ranging but in most cases emphasised physical fidelity issues. The responses included: “the flight controls are too sensitive”, “the flight controls are not responsive enough”, “ It does not fly like the real Piper Cherokee, the climb rate is too slow“, “the placement of the radio stack is incorrect it needs to be relocated”. Many of these criticisms of the PCATD were investigated and were rectified where it was possible to do so (e.g., flight model improved, instrument panel modified, installation of flight-control software filter). Instructor feedback was constantly sought after rectifications had been made to ascertain if they felt that there had been improvements in the user interface or fidelity.

6.3.7 Discussion

The design and development of the Stage 3 SAV1 PCATD was undertaken to fill a training gap at a university flight-training school. There was a need to provide a low cost PCATD that could be used for VFR navigation rehearsal and VFR remedial training. Expensive full flight simulators can recreate exact visual cues and precise instrument operation (i.e., physical fidelity). Low cost PCATDs still require a certain level of physical fidelity but the design is more focused on interactivity (i.e., functional fidelity) across a range of users in a variety of locations (Lewis & Jacobson, 2002).

Previous studies had focused almost exclusively on the effectiveness of PCATDs for instrument flight training. Only a few studies had examined the effectiveness of PCATDs for VFR training (Keller, et al., 2003; Lintern, et al., 1997; Roessingh, 2005) . These studies and others had indicated that some limited training benefits could occur when PCATDs were used for VFR training. Nevertheless, fidelity issues relating to FOV, display resolution, terrain resolution, and flight control response, limited their effectiveness for VFR training. The development of the Stage 3 PCATD was an attempt to address these physical fidelity issues through innovative and low cost design. Low cost technologies incorporated into the design had not formally tested by flight schools for VFR training (Go Flight, 2010; Nvidia, 2010; PFC, 2004).

The success of this low cost design methodology led to the investigation by other developers into the feasibility of designing low cost PCATDs (L. Schultz, personal communication, 21 Aug 2008; M. Hartley, personal communication, 20 Jan 2008).

It would be some time before established flight simulator manufacturers would see the benefits in deploying low-cost PCATD training technology for VFR training. Commercial FTDs and research based PCATDs based on a similar multi-screen design and using similar COTS components would not be developed for VFR training for at least another three to four years (Khan, et al., 2006; KiwiFlyer, 2012; Pacific Simulators, 2012; Redbird, 2010). A critical exercise was to establish if the Stage3 SAV1 PCATD was fit for purpose and not just a proof of concept. At the completion of the project, an evaluation exercise was conducted by senior flight instructors at the school to ascertain if the Stage 3 SAV1 PCATD was suitable for VFR training. Although the evaluation group was small, they had significant levels of flight instruction experience and fulfilled the criteria of SMEs on the type of aircraft simulated in the PCATD simulation.

The evaluation was in two parts. The first part was a practical examination of the task fidelity of the PCATD. This cognitive walkthrough method is based upon the evaluation theory of learning by doing (Wharton, Bradford, Jeffries, & Franzke, 1992). The second part consisted of the instructor performing a heuristic evaluation. Overall, the results of the cognitive walkthrough indicated that the instructors felt that the PCATD could be effective for training students on basic VFR exercises. However, the low default terrain resolution identified in the heuristic evaluation was a significant barrier in performing effective VFR navigation rehearsal, and to a lesser extent, rehearsal of the other two advanced VFR exercises. The solution to this issue of inaccurate terrain, was to increase the terrain resolution to 76-metre (Level of Detail 9) by installing into the PCATD, third party NZ mesh scenery (Stock, 2006). A key enhancement was to overlay the NZ terrain mesh with commercial software that generates an accurate 50-metre resolution topographical land class of NZ (Stock, 2005). These two measures not only improved visual accuracy of terrain features such as mountains, and rivers, it also improved the accuracy of topographical data such as bridges, power lines, roads, and small airfields. Further evaluation of the terrain mesh was undertaken with the flight instructors re-flying VFR navigation sorties with reference to VNC charts.

Eventually the mean rating of the evaluators in relation to Statement 2 was upgraded to a mean response of Moderately Agree. Despite the initial low rating of the terrain resolution, there was a positive evaluation of the user interface and fidelity of the PCATD in other areas such as flight controls, field of view, flight modelling, and instrument panel fidelity. The flight controls were FAA approved in terms of fidelity but most of the evaluators subjectively felt that they were more sensitive in terms of response than the aircraft flight controls. A study by Beringer (1996) supported the flight instructors' evaluation of the flight controls. In Beringer's study, pilots were asked to compare the PCATD flight control fidelity to the real aircraft. Most of the users found the PCATD flight controls to be more sensitive and more difficult to operate. Some FTDs in the flight school's inventory did have servo-controlled force feedback built into their flight controls but the technology was complex and costly (Frasca 2012). The cost of developing similar flight controls for the Stage 3 SAV1 PCATDs would have exceeded the financial resources allocated to the project. The problem with the flight control sensitivity was addressed by adjusting a number of software parameters that affected the response rate of the flight controls. Subsequent feedback on these changes indicated that there some improvement in the feel of the flight controls. However, the flight-control sensitivity could not be completely resolved. Pilot trainees had to adjust their fine motor control inputs when using the PCATD.

The overall evaluation by the flight instructors was that the flight control sensitivity and the lack of force feedback did not disqualify the PCATD. They believed that it was more effective in supporting VFR procedural training and less effective at developing the psychomotor skills of VFR flying. One instructor stated, "The aircraft is still the best training platform for training psycho motor skills as even full flight simulators cannot accurately replicate all of the sensory inputs of flight." This is supported by Denis & Harris (1998) who concluded in their study "the results suggest that PC-based flight simulators do not aid in the psychomotor skills required to fly a light aircraft. Their benefits lie elsewhere" (pg. 277). The field of view of the PCATD's visual display was evaluated as acceptable for VFR training and the peripheral views it provided was commented on favourably by the instructors.

There was quite a lot of discussion concerning the flight modelling of the simulated aircraft. It is quite difficult to adjust the flight modelling parameters to hit the numbers. The evaluators felt it was critical that the simulated aircraft had the correct climb and descent rate, roll rate and behaved aerodynamically like the real aircraft. In some cases, this measurement was quite subjective and depended on a number of factors such as height, entry speed into the manoeuvre, and wind speed. The solution was to pre-set a number of customised flight situations in the PCATD. The next step was to ensure that flight instructors and students used them exclusively when commencing a simulated VFR training exercise. The instrument panel display was perceived by the instructors to be too cluttered for VFR procedural exercises and this was substituted with a more simplified display. The conclusions gained from the design, development and evaluation of the PCATD was that the SAV1 PCATD could be used for effective VFR training in the following ways:

1. Solo rehearsal of VFR navigation exercises by pilot trainees;
2. Solo rehearsal of VFR exercises and procedures;
3. Training and assessment of VFR navigation exercises by an instructor;
4. Training and assessment of VFR remedial exercises by an instructor.

These recommendations were presented to the aviation school and the PCATD was formally adopted into the training programme. Remedial VFR training commenced almost immediately. One flight instructor in particular, completed over twenty hours of remedial instruction on tasks such as VFR cross-country navigation, landing flare, forced landings, and situational awareness training (B. Pete, personal communication, 14 June 2007). One cross-country navigation exercise was flown hundreds of times in the PCATD for training purposes. This eventually became an assessed PCATD sortie inserted into the VFR syllabus of training (see Appendix J1). This sortie was a VFR navigation exercise, and the route was from Palmerston North to Dannevirke to Masterton. Pilot trainees were required to complete the following tasks:

1. Brief the flight instructor;
2. Produce the correct navigation plates;
3. Fly the correct route using the correct VFR navigation procedures;

4. Replicate the correct radio calls;
5. Calculate Top of Climb (TOC) and Top of Descent (TOD) checks;
6. Brief the flight instructor while en-route.

The PCATD was an integral part of the training programme and it is estimated that 240 students (120 from each flight centre) would have completed the assessed navigation exercise. This PCATD exercise would then have been replicated as a cross-country exercise in the aircraft. The development of the PCATD for VFR navigation rehearsal and VFR remedial training had achieved its objectives.

6.3.8 Future development of Stage 3 SAV1 PCATD

The Stage3 SAV1 PCATD was formally adopted into the flight-training programme, and was used as a training aid for several years. Some limitations in its functional and physical fidelity became apparent as more flight instructors and students trained on it. Feedback from them indicated that the use of multiple keyboards (one per computer), lack of a cockpit surround, and the presence of multiple computers did reduce their perception of immersiveness while using the PCATD. Immersion refers to the degree to which an individual feels absorbed by or engrossed in a particular experience (Witmer & Singer, 1998). In terms of the physical fidelity, the flight controls required frequent re-calibration to maintain accuracy and although they were dual controls they were not physically linked. This was not a major issue as the emphasis was on training VFR procedures rather than psychomotor skills. On occasions, the instructors complained that students could not follow through on the flight controls when they were demonstrating a VFR manoeuvre or procedure. Also, a few errors in the topography of the terrain were discovered after intensive use of the PCATD and these would have to be addressed in any future development.

6.3.9 Stage 3 Project Extension: New Zealand Army UAV PCATD Project

6.3.9.1 Introduction

In 2007, the NZ Army commenced formal Unmanned Aerial Vehicle (UAV), also known as Unmanned Aerial Systems (UAS), training and recruitment. Training was conducted at the NZ Army ISTAR (Surveillance, Targeting. Acquisition, Reconnaissance) Battle Lab. As part of the UAV training, personnel from the NZ Army received practical aviation training up to PPL standard at the Massey University School of Aviation. The school was also tasked with assisting in the software design of three desktop PCATDS to assist the UAV operators with their PPL flight training. The desktop simulators were designed from COTS hardware and software and assembled at the Army Simulation Centre at Linton Camp, Palmerston North (NZ Army, 2007).

6.3.9.2 Background

Unmanned Aerial Vehicles are unpiloted aircraft of varying sizes and capabilities utilised by Defence Forces throughout the world. They are usually fitted with high-resolution cameras and/or other sophisticated sensors. Advanced UAVs, now have weapon capability and can undertake many different types of missions. UAVs provide an expanded view of the battlefield for ground and air commanders. They can be remotely controlled, fly autonomously based on pre-programmed flight plans or be controlled by dynamic autopilot systems (UAVS, 2012). These types of operations are already taking place in many countries. One of the significant UAV projects In NZ was the development of a UAV (KAHU) for the NZ Army (see Appendix K1). The Kahu UAV was designed with the following characteristics (SkyCam UAV, 2007):

1. Total Weight: 3.9 Kg, including payload;
2. Duration: 1 to 2 Hours;
3. Maximum Speed: 100 Km/h (Cruise – 60Km/h);
4. Wingspan: 2.2 metre composite;
5. Range: 25Km;
6. Hand launch take-off, automatic or manual landing;
7. Payload: Steerable Optical Camera, IR Camera (plus other sensors);
8. Maximum Altitude: 16,500 ft.

A Palmerston North contractor, Skycam NZ assembled the airframes and was contracted to maintain and repair them. Four UAVs with full motion video and vertical camera capability were developed as well as two ground control stations (Lee-Frampton, 2008).

6.3.9.3 UAV Operator Qualifications and Flight Training

A CAA seminar on the regulation of UAV operations in NZ indicated there was a consensus amongst attendees that UAV operators should have some formal flight training experience. It was suggested that this should be tied to existing pilot licensing levels. It was proposed that commercial UAVs required a minimum pilot qualification of a commercial pilot licence, with an appropriate type rating for the UAV being operated. The classification of UAVs was based on their Kinetic Energy ($^1/_2\ MV^2$). The mass variable M is calculated by using the Maximum Certificated Take-off Weight (MCTOW) and the velocity V by using the maximum air speed. For example, a UAV with a maximum energy level of 10,000 joules would require the operator to have a CPL (CAANZ, 2007b). However, for mini UAVs such as the KAHU design, the energy rating was a modest 740 joules. As the CAA had only made recommendations and had not published any definitive regulations there was some uncertainty as to the required level of general aviation training required by mini UAV operators.

The decision was then made in consultation with the Massey School of Aviation that pilot training to PPL level would be sufficient for NZ Army UAV operator training requirements (R. Harrison, personal communication, 20 June 2007).

6.3.9.4 PCATD Development & Utilisation

To assist with this pilot training programme, three PCATD procedural trainers were developed using the same flight software installed in the Stage 3 SAV1 PCATD. These PCATDs were for the sole use of the first UAV cohort that would undergo flight training (see Appendix K2). They were intended for use as training aids for unsupervised self-directed learning. This was the only practical way they could be used. The NZ Army base was located a considerable distance from the Massey School of Aviation flight-training centre at Palmerston North Airport. In addition, the PCATD procedural trainers had the potential to be a research platform to investigate different UAV flight models and to understand how UAV design could affect flight model characteristics.

6.3.9.5 UAV Operator/Pilot Training

Personnel from the NZ Army completed PPL training at the Massey University School of Aviation. The first group completed pilot training to PPL level that included a cross-country rating, and a night rating. The PPL flight training included (CAANZ, 2011e):

1. Total flight experience of fifty hours in aircraft;
2. Total solo time of fifteen hours in aircraft;
3. Five hours of instrument training in aircraft (two hours may be completed in an approved FTD or PCATD);
4. Ten hours of cross-country navigation training in aircraft;
5. Five hours of night flying in aircraft (including at least two hours solo flight time).

6.3.9.6 Informal PCATD Evaluation

The UAV trainees were able to rehearse PPL flight training sorties with a particular emphasis on navigation training and terrain awareness. They used FS2004 with customised aircraft (Piper Cherokee and Cessna 172) and the addition of high-resolution NZ scenery. The PCATDs used high-resolution LCD screens, which produced higher definition visual displays than the legacy CRT displays used in the Stage 1 and Stage 3 projects. Flight control sensitivity was an issue but was reduced by software filtering. Some of the trainees expressed reservations about the robustness of the flight controls but they proved to be reasonably durable. The LCD screen had an adequate level of resolution (1024x768 pixels) but the main limitation of the visual display was the limited field of view (FOV). In this PCATD, the screen had to display terrain and the instrument panel simultaneously. The ab-initio trainees indicated that they found the virtual aircraft model was similar enough to the Massey Aviation aircraft to be useful for basic VFR training.

6.3.9.7 Other Training Tasks

The Kahu UAVs also come with two Ground Control stations with simulation support that uses X-Planes Software to replicate flight performance. Captain Harrison (UAV Project Leader) explained that:

> Simulation allows basic skills to be refined, weather can be simulated, and the displays give a true reflection of the UAVs behaviour. Each student has two laptop displays showing moving map displays and a tail view of the UAV although displays can be switched to show other images, including video. All simulated flights are entered in the student's logbooks; it's an excellent way to train and a good way to keep currency" (Lee-Frampton, 2008, pg. 1).

Several experimental flight models were initially installed into the PCATD database. These models allowed trainees to investigate flying MSFS compatible aircraft designs and to analyse the unique flying characteristics of small to medium sized UAVs. However, software that was more suitable for this purpose was installed at a later stage. RealFlight 6.5-Radio/Controlled Flight Simulator allows the operation of a virtual, radio-controlled aircraft in a graphic environment similar to the 3D terrain depicted in MSFS (RealFlight, 2011).

6.3.9.8 Discussion

The PCATDs were required for two training tasks: PPL rehearsal training, and virtual UAV experimentation. To provide this functionality two software packages were installed on the PCATD computer. These packages included MSFS, and RealFlight 6 Radio Controlled Simulation software. Although there were limitations in the fidelity of the display (single screen) and the flight controls, there was positive feedback about the training benefits of the PCATDs.

Williams (2006) stated that unsupervised PCATDs (i.e. without direct flight instructor oversight) can benefit trainees for self-directed learning exercises. Pilot trainees can use the PCATD to review specific concepts and skills and practice procedures. FS2004 software was particularly flexible for these PCATDs because it included a learning centre, interactive flight tutorials, and flight challenges set at varying degrees of difficulty. All of these additional training tools can be used effectively for self-directed learning. Dunlap and Tarr's (1999) investigation of IFR/VFR scenario based training using MSFS 98 resulted in improved training outcomes. Subsequently, students were encouraged to participate in unsupervised training by being issued with customised CD-ROM based flight simulation vents (Brewin, 2000).

With a small number of NZ Army UAV pilot trainees (5) accommodated some distance from the flight training centre, the installation of customised PCATDs at their location for solo rehearsal and unsupervised PPL training was a useful training aid. This contributed to a high pass rate for the PPL flying course by the first cohort.

6.4 Stage 4: Development of the SAV2 PCATD for VFR Training

6.4.1 Introduction

Aviation training organisations have continued to investigate ways in which they can provide efficient and cost effective flight simulation to reduce training in the aircraft (Allerton, 2009). The development of full flight simulators and flight training devices is now a mature industry that supports flying training throughout the world. Nevertheless, the cost of acquiring and maintaining these devices is still beyond the financial resources of most flight training schools. In the last decade, advances in PC-based software and hardware systems have enabled designers to build cost effective PCATDs (CKAS Mechatronics, 2010; Elite Simulation Sytems, 2003; Ruscool Electronics, 2011). These devices can provide simulation training that is as accurate and effective as FTDs.

This was demonstrated in the first three stages where limited funding was available but there was a recognised need for training devices to assist with the training curriculum. In Stage 1, a PCATD was developed for fixed wing IFR/VFR flight training in an Air Force pilot training squadron. The second stage involved the development of a PCATD for rotary wing VFR & IFR flight training in a Helicopter Rescue Service. In the third stage of development, two identical PCATDs were developed for VFR navigation and remedial training in a University flight training school. External validation had been achieved with the Stage 2 PCATD when it was certified for IFR/VFR training by CAANZ. Action research methodology was adopted to develop instruments to evaluate the design and training effectiveness of these devices. Feedback from the evaluations provided impetus for the incremental improvement of the PCATDs at each stage of development.

The objectives of the Stage 4 project were twofold. First to improve on the VFR training capability of the Stage 3 PCATD by designing a new PCATD with the use of new visual display technologies, avionics controls, and new software tools. The second objective was to use the new Stage 4 PCATD as a research platform to compare its effectiveness for VFR flight training to a CAANZ certified FTD. The purpose of this comparative study was to provide additional evidence of the training effectiveness of a PCATD for VFR training. In the past, there had been an increase in the number of studies examining the training effectiveness of PCATDs for IFR training but only a few that focused specifically on VFR training (Roessingh, 2005; Rogers, et al., 2009).

In the first stage of the PCATD development, a comprehensive database of software and hardware tools were developed and adapted for use in each subsequent stage. At each stage of development, incremental improvements were applied to the user interface by the introduction of new low cost COTS technologies. There was a common theme linking these different stages of PCATD development. The evaluations had indicated that the PCATDs were more effective when used for IFR training than VFR training. In the first two stages, the difficulties encountered when using the PCATDs for VFR training were mainly attributed to limitations in visual fidelity, especially FOV, and flight control fidelity. In Stage 3, these issues had been partially addressed by the installation of multi-screen displays, improved terrain resolution, and more responsive flight controls. The use of individual PC's to drive each visual display was inefficient and this design feature was replaced with improved display technologies in Stage 4. To implement the Stage 4 development, multi-station PCATDs developed in Stage 3 were decommissioned. Some of the original components were recycled into the new Stage 4 design, which consisted of a single station PCATD upgraded with new software and hardware technology.

6.4.2 Literature Review

There are a large number of studies comparing training transfer (fixed wing) between PCATDs, FTDs, and aircraft in relation to instrument training. A few examples are (Beckman, 1998; McDermott, 2005a, 2005b; Rantanen & Talleur, 2005; Stewart, 2001; Taylor, et al., 1999; Taylor, et al., 2003; Taylor, et al., 2004). Significantly, fewer comparative studies have examined training transfer in relation to VFR task training (Dennis & Harris, 1998; Khan, et al., 2006; Lintern, et al., 1997; Roessingh, 2005; Rogers, Boquet, Howell, & DeJohn, 2007; Rogers, et al., 2009; Williams, et al., 1996). The VFR related studies are also quite diverse and have investigated ab-initio tasks, landing, aerobatics, upset recovery, and out- of- cockpit-window cues.

6.4.2.1 Comparative Studies of VFR Training Transfer between PCATDs, FTDs, and Aircraft.

In the past, the design of flight simulators for pilot training was driven by the assumption that the more fidelity a simulator has, the better the training. However, this view has changed significantly in the last two decades. Positive transfer to the aircraft has been demonstrated with low cost, low-fidelity, PCATDs in a number of experimental transfers of training (TOT) studies that have focused on ab-initio training (Dennis & Harris, 1998; Lintern, et al., 1997; Taylor, et al., 1999; Taylor, et al., 2004). All of these studies have demonstrated positive transfer for standard flying tasks, such as basic instrument tasks, visual landings, and visual turns, in the ab-initio stage of flight training.

Two of the ten IFR flight lessons in Taylor, et al’s (1999) study involved VFR flight lessons in training steep turns. The control group, which only received training in the aircraft, needed on average 3.83 steep turns to reach acceptable performance. The experimental group, after being trained with the PCATD, needed on average 3.40 steep turns in the aircraft. There was no significant difference in the number of trials required to achieve the criterion performance level between the control group and experimental group. However, when expressed in flight time, the control group needed on average 1.52 flight hours to demonstrate acceptable steep turns and the experimental group needed on average only 0.95 flight hours a significant difference of 0.57 flight hours. Therefore, the main significant advantage in training for steep turns by the experimental group was supported by their more efficient use of flight time.

In Roessingh’s (2005) study, three groups of novice pilots received training to fly aerobatic manoeuvres in a light aircraft. The groups were randomly assigned to the following conditions: normal treatment (the control group), ground training with a standard PC-configuration (the “S group”), and ground training with a PC-configuration with extra features (the “X group”). The trainees assigned to the control group were given briefings before receiving in-flight instruction. Trainees in the two experimental groups received extra training: Each in-flight lesson was preceded by a PC-based simulated flight. Approximately, 2,000 manoeuvres were analysed, based on both flight-data recordings, and instructor ratings. The results differed from other transfer of training studies in that the results indicated no significant differences in flying skills between the three groups as measured by the flight-data recordings. Roessingh thought that this might be due to systematic qualitative differences between the type of training provided in this experiment and that provided in studies that have reported a positive transfer-of-training effect. However, there was a marginal advantage in this training programme, in that pilot trainees needed less briefing time from the instructor after every fifty minutes of simulation.

Rogers, et al. (2009) reported significant training transfer using low-cost simulation to teach upset-recovery manoeuvring to general aviation pilots with no prior aerobatic experience. Participant pilots were trained using MSFS running on low-cost desktop computers, and then tested in an aerobatic Super Decathlon aircraft. Statistical analysis confirmed that low-cost simulator based upset-recovery training improved pilot performance in recovering an aircraft from an unusual attitude. Trained pilot performance exceeded untrained pilot performance in 16 of 23 dependent measure categories, or 69.6% of the time. Trained participants lost less altitude than control group pilots did in all four unusual attitude positions, and two of the four altitude differences were statistically significant. Trained pilots initiated rolls toward a wings level and upright attitude sooner and applied more G forces in dive pull-outs than untrained pilots apply. These are both critical factors in minimising altitude loss. In addition, trained pilots also applied throttle more promptly than untrained pilots did. These differences, in turn, resulted in a quicker return to straight-and-level flight.

Leland, Rogers, Boquet, & Glaser (2009) then expanded on this initial study. Two groups of participants were given simulator-based training in upset-recovery, one in a high fidelity motion based flight simulator, the other using MSFS running on desktop computers. A third control group received no upset-recovery training at all. All three groups were then subjected to serious in-flight upsets in an aerobatic aircraft. Pilots from both trained groups significantly outperformed control group pilots in upset-recovery manoeuvring. There were only minimal differences between pilots from the two treatment groups. The results indicated that responses to upset-recovery manoeuvring could be taught as effectively with MSFS as with the motion based GL2000 simulator using proprietary software. The first of these responses involved using visual cues to determine pitch and bank angles during an upset. A feature of this study was that the Desktop simulator did provide multi-screen views. These views consisted of three simultaneous outside- the-cockpit views: 90 degrees left, front facing forward, and 90 degrees right.

6.4.3 Development of Stage 4 SAV2 PCATD for VFR Training and Research

After the two Stage 3 PCATDs were decommissioned, a number of components were retained for use in the new Stage 4 PCATD project. These included the relatively high fidelity Precision Flight Controls (Yoke, Throttle Quadrant, and Rudder Pedals) and the Go Flight Radio & Navigation (Avionics Modules). One of the limitations identified in the Stage 3 SAV1 project was the use of an individual computer for each visual display.

Although relatively low cost, it resulted in the PCATD having a large footprint and complex network synchronisation to run correctly. In the Stage 3 project, multi-screen instrument panel displays were achieved with low cost first generation Matrox[24] splitter technology (Matrox, 2005). In this Stage 4 project, a second-generation digital Matrox splitter had been developed which was powerful enough to drive multi-screen displays for out-of-cockpit views. A feature of low cost visual display technologies is the rapid advancement in capability of this type of equipment. FTD manufactures tend to be more conservative and upgrading their proprietary hardware and software requires significant capital investment in research and development. Therefore, major design changes are on a much slower cycle than low cost development. The adoption of low cost technologies is

[24] The Matrox DualHead2Go Digital SE external multi-display adapter can add up to two monitors to your laptop or desktop computer. It connects to the video output of your system and uses the system's existing GPU to provide high-quality video across all monitor s (Matrox, 2012).

more flexible but also carries more risk as compatibility issues with components from different manufacturers can create problems.

6.4.4 Microsoft Flight Simulator 2004 Aircraft Model

The Microsoft Flight Simulator aircraft used in the Stage 4 PCATD project was constructed with five key software components:

1. **The model**. This is a 3D CAD-style model of the real aircraft's exterior and virtual cockpit (see Fig, 6-13, 6-14).
2. **The model textures.** These are bitmap images, which are layered over the aircraft model and can be easily customised to represent an aircraft livery (see Fig. 6-14).
3. **The sounds**. These are in WAV format and simulate an appropriate sound set for a particular aircraft.
4. **The panel.** This is an interactive representation of the real aircraft panel. The flight simulator software outputs flight simulation data through the instrument gauge files (see Fig. 6-15, 6-16).
5. **The Flight Dynamics Engine (FDE)**. This file contains hundreds of parameters that define the aircraft's flight characteristics. The MSFS FDE is designed so that the visual model and the flight dynamics model are separate entities. The simulator engine uses data from look up tables that contain the appropriate aircraft flight parameters. These tables contain all the values that are necessary to replicate the flight behaviour of the real aircraft. The flight simulator engine then calculates the forces and velocities that act on the aircraft and moves it accordingly.

The stability and control of the aircraft flight models used in MSFS are defined by non-dimensional aerodynamic coefficients. These coefficients are defined as a linear-representation of the simulated aircraft aerodynamic forces and moments. When these values are used along with the aircraft geometry, mass and dynamic pressure, they can be solved for the over-all forces and moments for an aircraft. MSFS also uses a high fidelity

Piston Engine simulation which combines variables such as RPM, shaft torque output, engine friction, and mechanical efficiency. The propeller simulator is also complex and must simulate variables such as constant speed, feathered props, and synchronisation (Zyskowski, 2010).

Figure 6-13. Massey School of Aviation Piper Warrior

Source: (Pardon, 2005) - Picture of the Piper PA-28-161 Warrior II Aircraft. Retrieved from http://www.airliners.net/photo/0914599/

Figure 6-14. FS2004 Compatible Piper Warrior Flight Model & Visual Model

Source: FS2004 Massey SOA Piper Warrior Repaint
Retrieved from Andrew.Underwood89@gmail.com

Figure 6-15. Massey School of Aviation Piper Warrior Instrument Panel

Figure 6-16. Example of Microsoft Flight Simulator Compatible Piper Warrior Instrument Panel

Source :(Spada, 2007) Piper Pa28 Freeware. Retrieved from http://library.avsim.net/download.php?DLID=104805.

6.4.4.1 Visual Display

The visual display resolution (less than 30 pixels per inch) of the Stage 1 project and the single screen size of the Stage 2 project (45 inches x 11.4 inches) was significantly improved in the Stage 3 project.

The visual display consisted of three major components:

1. Multiple screens were used for the out-of-cockpit-view. A 35-inch Liquid Crystal Display (LCD) main view screen was combined with two 19-inch LCD side-views. LCD screens have several advantages over CRT displays, especially the type used in Stage 4. LCDs consume less power, take up much less space, and are considerably lighter. The common active matrix LCD technology also has less flickering than CRTs, which reduces eyestrain. Using these LCD screens provided a screen size with the following dimensions. A total horizontal base of 61.72 inches with a 20 inch height (53 ppi) on the main screen, and 9 inch height on the side screens (93 ppi). The display resolution of these screens was set at 1280x1024, the same resolution of the Stage 3 PCATD.
2. Keller, Schnell, Lemos, Glaab, & Parrish (2003) suggested that a high PPI value for visual display resolution improves pilot performance but this can be expensive to achieve using large screen sizes. There were several advantages that LCDs have compared to the CRT displays used in Stage 3. LCDs consumed less space, were considerably lighter, and generated greater levels of visual resolution (PPI). The LCD screens also exhibited less flickering than CRTs, which reduced eyestrain.
3. The utilisation of third party software (Active Camera) provided scan capabilities and snap views, which increased the field of view to 170 degrees (Middleton, 2006). In addition, activation of this software was linked to a push button situated to the yoke controls. The software allows a number of preset views so that moving to different cockpit viewpoints is automated with the push button. Another button on the yoke was programmed to provide a zoom function for the cockpit view.

4. An additional screen 19-inch LCD was used for the instrument display (see Fig. 6-17). Finally, a 19-inch LCD screen and networked PC was used as an instructor station.

The display system with one front screen and two smaller side screens was designed to replicate the large front view and limited side views of the Piper Cherokee training aircraft used at the university aviation school (see Fig. 6-17). By utilising multiple screens and the Active Camera software, the PCATD produced a FOV up to 220 degrees.

Figure 6-17. Stage 4 SAV2 PCATD Multiple Screens

In the Stage 3 and Stage 4 project, the MSFS software could provide pan views and snap views that could extend FOV. The Active Camera view was more realistic and matched the 120-170 degree field of view that was produced by the Frasca TruFlite FTD visual display, although on a smaller screen size. To ensure consistency in the comparative study the visual capabilities of the PCATD were matched as closely as possible to the visual FOV capabilities of the Frasca TruFlite FTD. When practising VFR procedures in the PCATD it is essential that the pilot trainee has a FOV of at least 120 degrees from any location while executing the required manoeuvres (Keller, et al., 2003).

In addition, the terrain database of the PCATD is customised with add-on NZ scenery and is far more detailed than the generic terrain database found in the Frasca TruFlite. To ensure visual compatibility between the two devices the terrain level of detail in the PCATD was reduced for the purposes of the comparative study.

6.4.5 Communications and Navigation Radios

Williams (2001b) outlined comprehensive FAA qualification guidelines for the use of PCATDs for Private Pilot Licence training. These include:

1. Physical or virtual controls for communications radios, NAV radios and VOR;
2. Physical communications radio microphone or push-to-talk switch;
3. Display of navigational radio and VOR with an aural, Morse code identification feature.

In the Stage 1 project all flight instruments, including communications and navigation radios were virtual (i.e., displayed on a CRT screen). In Stage 2 and Stage 3, the flight instruments were digital replicas projected on to a monitor screen but communications and navigation radios were physical replicas. The physical simulation of communications and navigation radios was made possible with the commercial development of low cost replica modules by companies such as Go Flight (Go Flight, 2010) and VRinsight (VRinsight, 2012).

In Stage 3, a Go Flight GF-46 Display module was used for radios, altimeter, transponder, and other MSFS functions that require a display of data. For the Stage 4 project, individual GF-166 Radio Panels were used. Both projects also used these units in combination with first-generation modules such as the GF-P8 Push Button Module and GF-RP48 Pushbuttons and Rotary functions Module. The use of these modules significantly increased the physical and functional fidelity of the PCATDs designed in the Stage 2-4 projects. Evaluators of the PCATDs in Stage 2 and Stage 3 indicated that they were more functional and realistic than using virtual instruments to replicate avionic functions (D. Walley, personal communication, 10 June 2008). For the Stage 4 project, a Go Flight

Integrated Communications Console System was used to simulate the communications and navigation radios. Development of these modules within the project would have been prohibitively expensive and therefore COTS technology had to be sourced from overseas companies like Go Flight. Similar companies had begun to produce a variety of low cost instrument console systems that were MSFS compatible, which could provide additional fidelity for PCATDS. Although most first generation modules were generic, later designs have become increasingly complex and realistic (PFC, 2012). This is one area where the fidelity gap between PCATDs and FTDs has been successfully bridged by continual incremental improvement in design.

6.5 Evaluation of Stage 4 PCATD for VFR Training

This section establishes the theoretical framework for this study. In addition, the desired participant group was identified and the experimental apparatus described. The research questions were proposed, the study design outlined, and the procedures that were used described. Data analysis is then discussed. The assumptions and limitations related to pilot trainees completing advanced aeronautical manoeuvres in an FTD and PCATD are also discussed.

6.5.1 Research Gap

Many studies have investigated the training transfer of PCATDs for instrument training (Beckman, 2009; Taylor, et al., 2003) but this has not been matched by a similar level of research into VFR training in PCATDs (Schneider, et al., 2001). This has been mainly due to the limited visual fidelity and flight control fidelity of PCATDs. Embry-Riddle University established that the use of FTDs with high fidelity visual displays and aircraft flight modelling did show a positive transfer of training for ab initio pilots undergoing visual flight training (Macchiarella, et al., 2006).

The relatively low fidelity of PCATD flight controls, visual fidelity, and flight modelling meant that they were not recommended for training ab-initio pilots in VFR flight-control handling. However, the fidelity and complexity of PCATD hardware and software has markedly improved in recent years. Consequently, the extent to which they can be used for

VFR training requires further examination. Stages 1-3 have demonstrated incremental improvements in the fidelity and training effectiveness of PCATDs. Therefore, a comparative study using the Stage 4 PCATD and a CAANZ certified FTD (Frasca TruFlite) would provide additional evidence in support of the use of PCATDs for VFR training.

6.5.2 Methodology

A variation of a transfer of training study is a quasi-transfer study. Utilising a real aircraft can be expensive and time consuming, so an alternative method was quasi-transfer. A quasi-transfer of training study differs from a traditional study in that a high fidelity FTD is used to test both training and transfer tasks. One group will train on a high fidelity flight simulator and the other group will train on an experimental flight simulator. The two groups will then transfer to the high fidelity flight simulator that represents the real aircraft (McDermott, 2005a). A quasi-transfer of training study is easily replicable and can be performed for a wide variety of tasks. The methodology adopted for this study is the Three Group-Control Group Design, which has a high level of internal validity. In the first stage of this experimental design, participants are randomly assigned to one of three groups (the two experimental groups, or the control group). In the second stage, a pre-test is administered to each group. One group is designated as a control group and the other two groups are given a specific experimental treatment. Finally, each group of participants is given a post-test.

The main question is whether the results of quasi-transfer studies are relevant to flight training in which performance in the aircraft constitutes the criterion. Quasi-transfer studies have been used successfully in a number of experiments; to test augmented information as an instructional variable for landing (Lintern, 1980; Lintern, Roscoe, & Sivier, 1990) and for air-to-ground attack (Lintern, Thomley, Nelson, & Roscoe, 1987). They have been used to examine scene detail for out-of-cockpit visual scenes (Lintern & Koonce, 1992) and the effect of simulator platform motion (Go, 2000). The advantage of quasi transfer design is that when used with ab initio pilot trainees it can be used to determine the level of training transfer with minimal interference from the effects of prior flight experience (Taylor, et al., 1993).

This study represents a three-group pre-test/post-test quasi-transfer experimental examination of pilot proficiency in VFR procedures. In this design, most interest is in determining whether the three group's post-test results are statistically different after their respective simulator training sessions. The adoption of a pre-test/post-test design that includes a control group and random assignment will help to ensure that treatment effect is not linked to individual characteristics (Garcia-Diaz & Phillips, 1995). The experimental study was comprised of two parts:

1. Is the Stage 4 SAV2 PCATD as effective as a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation?

2. Is there a significant difference in performance of a standard VFR traffic pattern operation on the Stage 4 SAV2 PCATD between pilots with different levels of aviation experience and from two different flying training organisations?

This study sought to determine the effectiveness of a PCATD compared to a CAANZ certified FTD at improving pilot proficiency in VFR procedures. The experimental task involved the execution of a standard VFR traffic pattern operation (i.e., a standard overhead rejoin manoeuvre). The learning transfer that took place was measured to ascertain the effects on task performance by measuring eight dependent variables while executing the traffic pattern operation:

1. Altitude;
2. Magnetic Heading;
3. Pitch;
4. Bank;
5. Airspeed;
6. Total Score;
7. Glideslope;
8. Pattern (Categorical).

The measurement of these dependent variables provided accurate primary information about the performance of the following pilot skills:

1. Maintaining correct altitude;
2. Maintaining correct magnetic heading;
3. Maintaining correct attitude;
4. Implementing procedural turns;
5. Maintaining correct airspeed;
6. Overall performance;
7. Intercept and maintain Glide Slope;
8. Implementing a correct Overhead Rejoin pattern.

6.5.3 Participants

Forty aviation-training organisations in New Zealand were identified as having a primary role of pilot training. Results of a survey indicated that there is an estimated population of 1,300 pilots at various stages training in NZ. The majority of the participants of this study included general aviation pilot trainees and university students who were undergoing training up to and including PPL level. In addition to undertaking flight training, the trainees and students had completed a wide variety of aviation related subjects that included meteorology, principles of flight, navigation, human factors and aviation law. The participants selected for this study were chosen from a pool of candidates that came from:

1. A university aviation training organisation located within the local geographic area of NZ (estimated population -100 trainee pilots);
2. An aviation-training organisation located in a major city of NZ (estimated population -200 trainee pilots);
3. Smaller aviation training organisations within the local geographic area of NZ (estimated population -50 trainee pilots);
4. Other aviation organisations based in NZ (estimated population -1200 trainee pilots);
5. A local university (small sample of pilots with very limited experience).

Trainee pilots from Group 1-2 were selected for the study because they belong to two large NZ FTOs (Massey University Aviation School & Ardmore Flying School) that operated the same model of a Frasca TruFlite FTD. In addition, their practical flight training programmes were very similar and their student populations had similar demographics. Group 3-5 candidates belonged to educational organisations or aviation training organisations that did not own or have ready access to a PCATD or FTD for training purposes. Therefore, they were invited to travel to the Massey University Flight Training Centre or the Ardmore Flying School (whichever training centre was closest to them) to participate in the comparative study. For example, pilots who volunteered for the study from Flight Training Manawatu (Fielding) and Wanganui Aero Club had to drive approximately 30-60 minutes to reach the Massey Flight Centre. In the Auckland region, participants from the Auckland Aero Club were located only a few minutes' drive from the testing centre at Ardmore Flying School. Although the participants did not represent a true random sample of the population, they were purposively[26] drawn from a pool of candidates that represent approximately 22% of the NZ population of ab-initio pilots. Participants were then invited by mail to take part in the Stage 4 PCATD study (see Appendix L). Also included in the participation request was an informed consent form (see Appendix M) and a questionnaire about aviation experience (see Appendix N).

Participants in the study were drawn from the following organisations:

1. Ardmore Flying School;
2. Auckland Aero Club;
3. Fielding Aero Club;
4. Kingfisher Airlines;
5. Manawatu Districts Aero Club;
6. Massey School of Aviation;
7. No. 10 (City of Palmerston North) Air Training Corps;
8. Royal New Zealand Airforce;
9. Wairarapa Aero Club;
10. Wanganui Aero Club;
11. Massey University.

The Massey School of Aviation and Ardmore Flying School participants were ethnically and culturally diverse. Approximately 50% were foreign students who had applied for student visas to enable them to train in NZ. The majority of participants from the various aero clubs were NZ citizens with a small number of international students. The RNZAF and Air Training Corps participants were all NZ citizens. The candidates from Kingfisher Airlines and Massey University general student population were international students. A central aim of this study was to invite participants from a wide range of flying training organisations to avoid any threats to external validity. It was also crucial to strengthen external validity by replicating the study in different locations. A cohort of ninety-three participants (Research Question 1) and cohort of fifty six participants (Research Question 2), affiliated with the eleven different organisations (Groups 1-11) were recruited for the major study.In terms of professional flight experience, they ranged from airline pilots with thousands of flight hours, military trainee pilots, pilots who had just completed CPL or PPL certification, ab-initio pilots with less than ten hours of single engine flight time, and potential aviators who had only flown a few trial flights.

Participants' age range was 16-72. Eighty per cent were between 19-25 years old. Fifteen of the participants in the study were female. They had also undergone training at a variety of flying schools in NZ or overseas. In terms of flight-training hours, there was also a range of experience levels. Participants in the study included one experienced Boeing 737-800 pilot; two helicopter pilots, two military pilots, and one glider pilot. Two senior flight instructors and six junior flight instructors participated in part one of the study but this was balanced by ten participants who had very limited flying experience. The majority of participants in both parts of the comparative study were ab-initio pilot trainees. Most had only completed up to ten hours of flight training, and had minimal training hours on the PCATD and Frasca FTD. However, the participants in the second part of the study were not randomly selected and one group had significantly more flight training experience. This was a deliberate sampling strategy to establish if prior aviation experience affected VFR task performance in the Stage 4 SAV2 PCATD. A pre-test survey conducted amongst the participants comprised the following questions (see Table 6-15):

1. What is your total accumulated flight time?
2. What is your total accumulated VFR time?

3. What is your total accumulated FTD time?
4. What is your accumulated PCATD time?
5. What is your total accumulated recent flight time? (within previous two weeks)

Participants were recruited by face-to-face contact, mail, and phone. A copy of the request for participation in the comparative study and a consent form is outlined in Appendix L and M. Students training at local flight training schools including Massey University School of Aviation were approached first. Then students and instructors training at Ardmore Flying School, Auckland and other flight schools in that region were also approached.

Table 6-15. Participants Previous Aviation Experience (Aircraft, FTD, PCATD)

Total Flight Hours Experience	VFR Flight Hours Experience	Recent Flight Hours Experience	PCATD Hours Experience	FTD Hours Experience
60% (60 hours<)	63% (60 hours<)	67% (10 hours<)	94% (2 hours<)	88% (2 hours<)
30% (60-250 hours)	27% (60- 250 hours)	30% (10-30 hours)	3% (2-20 hours)	5% (2-20 hours)
10% (>250 hours)	10% (>250 hours)	3% (>30 hours)	3% (>20 hours)	7% (>20 hours)

6.5.4 Apparatus

6.5.4.1 Frasca TruFlite FNPT II FTD

The primary flight-training device used at the Massey University School of Aviation and the Ardmore Flying School was the Frasca TruFlite Flight & Navigational Procedures Trainer (Frasca, 2007). These two flight-training schools were the only organisations in NZ, at the time, that operated this particular Frasca model. The NZ CAA certified FTDs were an essential research tool for the comparative study. They were not only used to train some participants in VFR procedures but were also used to test all of the participants VFR task performance in the first part of the study. The VFR task performance of participants assigned to train on the FTDs was then compared to a second group of participants who trained on the SAV2 PCATD, and a control group that received no training on either device.

Frasca International manufactures flight-training equipment for airlines, flight schools, universities and military organisations worldwide. Their product range includes Flight Training Devices, Cockpit Procedure Trainers, and Full Flight Simulators for a number of aircraft types. Although the Frasca Truflite FTD is relatively expensive it is still a very popular flight training device. It was developed to meet the requirements for JAA FNPT devices in Europe and throughout the world. It uses Frasca's proprietary Computer Generated Instrumentation (CGI) and realistic overlays with bezels, screws, glass and knobs. The Frasca TruFlite is also a reconfigurable device that can be converted between a twin-engine general aviation aircraft and a single engine aircraft.

The Massey University School of Aviation currently operates a Frasca TruFlite FTD that is certified by the CAANZ for assessing pilot competency; in both IFR and VFR procedures (see Fig.6-20). The TruFlite FTD can be configured as a twin-engine Piper Seneca V or a single-engine PA-28 (Piper Warrior) but is primarily used for training towards multi-engine instrument ratings. It is normally configured as a two-seater cockpit with dual controls and a networked Graphical Instructor Station. The Ardmore Flight School currently operates a Frasca TruFlite FTD that is certified by the CAANZ for assessing pilot competency, in both IFR and VFR procedures.

The TruFlite FTD can be configured as a generic twin-engine aircraft or a single-engine aircraft and is primarily used for training towards multi-engine instrument ratings. It is normally configured as a two-seater generic cockpit with dual controls and a Graphical Instructor Station (see Fig.6-18). For the purposes of the comparative study, both FTDs were configured to emulate the performance characteristics (i.e., by limiting speed and adjusting flight model characteristics) of a single engine Piper PA-28 (Piper Warrior) aircraft (see Fig. 6-19).

Figure 6-18. Massey Aviation TruFlite FTD & Ardmore Flight School TruFlite FTD

The Piper PA-28 was the primary flight training aircraft used for ab-initio flight training for Massey Aviation. The primary training aircraft used for ab-initio flight training for Ardmore Flying School was the Cessna 172. For the majority of students they accumulated the most training hours in these aircraft and they were most familiar with these aircraft types. Although they were different aircraft model types, they had similar flight handling characteristics and instrument panel configurations. The Piper Cherokee flight model was selected for the comparative study because this aircraft type could be emulated on the Frasca FTD and the SAV2 PCATD.

Figure 6-19. Frasca FNPT II STD Single engine Mode

A set number of IFR assessment sessions (20 hours) completed on these two FTDs can be logged towards a multi-engine instrument rating and for instrument currency training. Its secondary functions include multi-engine type rating, single-engine instrument rating, and basic VFR procedures training (CAANZ, 2011a). The Frasca TruFlite also had a FAA Level 6 Qualification; an authentic aircraft cockpit; electric control loading; and uses the TruVision visual display system (Frasca, 2007). One limitation of the Frasca TruFlite visual display was that the visual system database did not contain NZ terrain data, and was limited to a visual inventory of NZ airfields with the correct location, size and orientation.

6.5.4.2 Graphical Instructor Station (GISt)

The Graphical Instructor Station (GISt) was a robust and versatile data collection tool for the comparative study. Flight performance variables were recorded and analysed. Virtually all previous transfer of training studies that have dealt with low-fidelity/PC-based simulation has used instructor ratings to measure flight performance. Despite well-defined rating criteria and standards, it is difficult to prevent unreliable flight instructor ratings (Roessingh, 2005). The analysis of flight data generated by GISt is a more objective and accurate measure of VFR task performance. GISt is a computer-based interface that uses a Graphical User Interface (GUI) to control the FTD. GISt contains a core group of functions (see Fig. 6-20). The functions that were used for this study were the:

1. Map Display;
2. Parameter Plots;
3. Record /Replay Flight;
4. NIFA Score Editor.

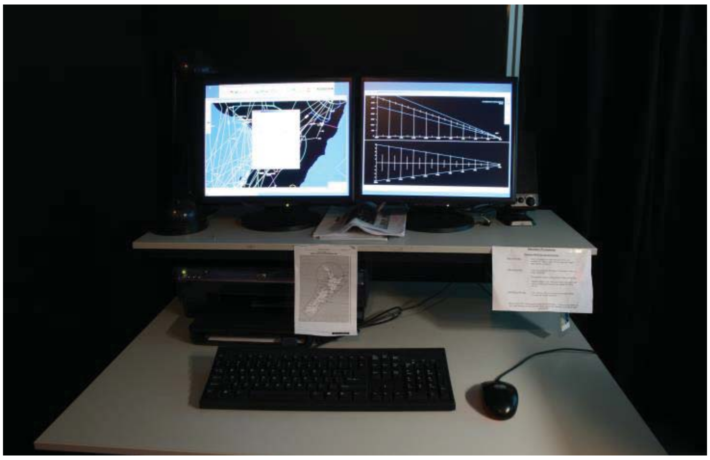


Figure 6-20. Frasca TruFlite FNPT II GISt Instructor Station

6.5.4.3 Map Display Module

The map display is a graphical display that depicts the aircraft's flight path. The Map Module Map provides a graphical display of the aircraft, its ground track, navigation stations, and reference grids, it also allows operator direct input for resetting aircraft location and flight parameters (see Fig. 6-21). The user can program the map to load automatically with GISt initialisation but this was inconsistent on occasions. Therefore, in this study, the map was loaded manually. This was to ensure that map settings such as location, magnification level, orientation etc. were standardised and identical for every participant. The map environment configured for this study was an airport based at Palmerston North but designed with generic features such as MSFS default buildings and runways.

Figure 6-21. Map Display Module

Source: Frasca. (2006). Operators Manual TruFlite (No. OMAN144711 Rev. M). Urbana, Illinois : Frasca.

6.5.4.4 Parameter Plot Module

Using the GISt Parameter Plotting Module, up to three values of a participant's training session can be recorded in a graphic display for view either on screen or in a printed copy (see Fig. 6-22). The four vertical lines identify the time elapsed in number of minutes.

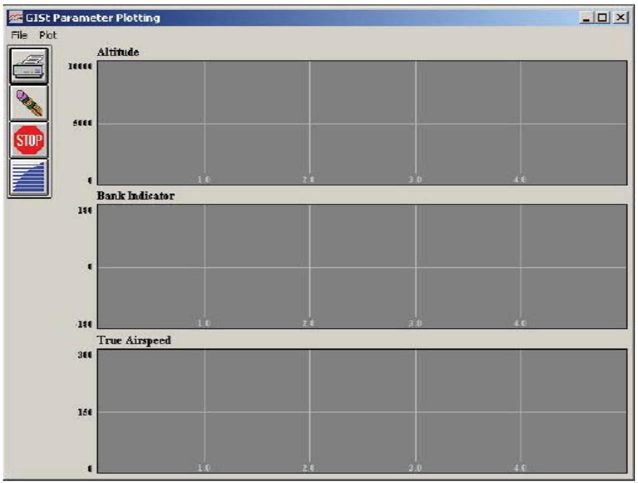


Figure 6-22. Parameter Graph Plot

Source: Frasca. (2006). Operators Manual TruFlite
(No. OMAN144711 Rev. M). Urbana, Illinois: Frasca

6.5.4.5 Record/Replay Flight

Using the GISt Record/Replay Module, participant's pre-test, training, and post-test training sessions were recorded for later review and analysis through the flight instruments, visual system, and GISt Map and Approach displays (see Fig. 6-23).

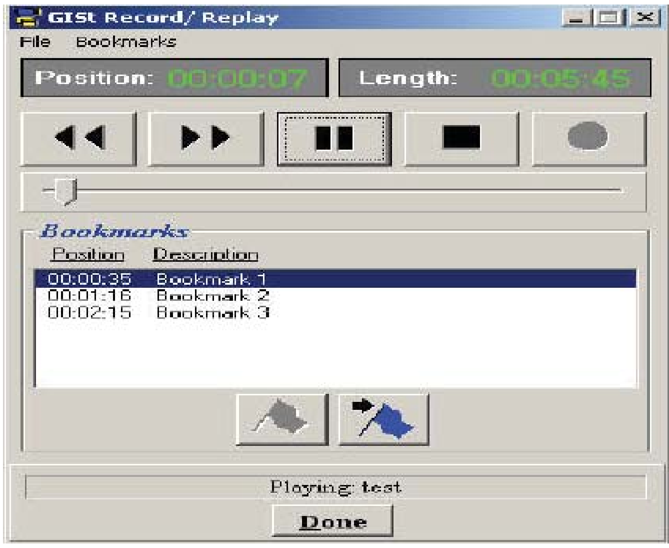
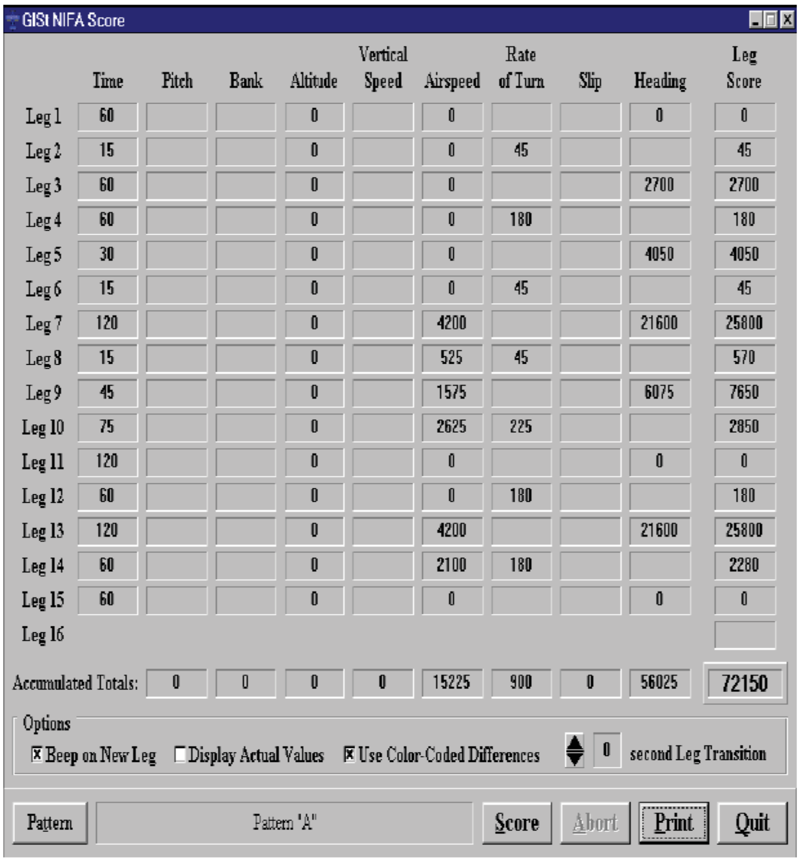


Figure 6-23. GISt Record/Replay Module

Source: Frasca. (2006). Operators Manual TruFlite
(No. OMAN144711 Rev. M). Urbana, Illinois : Frasca

6.5.4.6 NIFA Score Module/Editor

The NIFA Score Module originated as a program used by the National Intercollegiate Flying Association to measure and compare the performance of pilots as each attempted to fly an established flight pattern (See Fig. 6-24). This module permits recording the performance of different pilots—and that of the same pilot at different stages of training—with absolute objectivity. The NIFA score module records the number of errors committed by participants across a number of selected flight variables. A high score represents a high number of errors and therefore a poor performance.



	Time	Pitch	Bank	Altitude	Vertical Speed	Airspeed	Rate of Turn	Slip	Heading	Leg Score
Leg 1	60			0		0			0	0
Leg 2	15			0		0	45			45
Leg 3	60			0		0			2700	2700
Leg 4	60			0		0	180			180
Leg 5	30			0		0			4050	4050
Leg 6	15			0		0	45			45
Leg 7	120			0		4200			21600	25800
Leg 8	15			0		525	45			570
Leg 9	45			0		1575			6075	7650
Leg 10	75			0		2625	225			2850
Leg 11	120			0		0			0	0
Leg 12	60			0		0	180			180
Leg 13	120			0		4200			21600	25800
Leg 14	60			0		2100	180			2280
Leg 15	60			0		0			0	0
Leg 16										
Accumulated Totals:		0	0	0	0	15225	900	0	56025	72150

Figure 6-24. NIFA Scoring Editor

Source: Frasca. (2006). Operators Manual TruFlite

(No. OMAN144711 Rev. M). Urbana, Illinois: Frasca

6.5.4.7 SAV2 PCATD Instructor Station

The PCATD instructor station used two flight variable recording software packages (see .Fig. 6-25). The first package was a freeware application, Visor 2000. This software is capable of recording simulator-training sessions for playback and can record flight variables such as altitude, track, pitch, approach path, and vertical speed, and angle of bank. An additional software package FltRec that is compatible with FS2004 was used to play back recorded flights in real time and rescan flight variables if necessary. Visor 2000 can also display flight variables that are generated by FS2004 in a graphical form (Pardo, 2012). The software is flexible and can display a binary file produced by the Flight Data Recorder 8.0 (Fltrec) utility (Hernandez-Ros, 2012).

Figure 6-25. SAV2 PCATD Instructor Station & Visor 2000 Software

Visor 2000 converts the Flight Data Recorder 8.0 Fltrec.data file into two separate text files. The first file lists the maximum variables and flight conditions (see Fig. 6-26). The second file lists the following variables (see Table 6-16):

1. Time;
2. Latitude;
3. Longitude
4. Altitude;

5. Pitch;
6. Bank;
7. Track;
8. TAS;
9. IAS.

FLIGHTMAXIMUM C:\Documents and
Settings\sreweti\Desktop\visor2000\data****train2.dat
Date of this analysis: Thu Dec 20 14:24:46 2010
Initial time of the record: 15:57:14
2. MAXIMUM VARIABLES AND FLIGHT CONDITIONS
Variable Time Altitude Latitude Longitude Pitch Bank TAS
IAS
-------- ---- -------- -------- --------- ----- ---- --- ---
Altitude 15:58:15 **01564** -40.328 +175.608 +02.5 -21.1 0138
0109
Negative Pitch 15:59:05 01288 -40.343 +175.624 **-09.3** +25.5 0139 0114
Positive Pitch 15:58:25 01491 -40.334 +175.607 **+07.5** -03.5 0145
0115
Negative Bank 15:58:15 01564 -40.328 +175.608 +02.5 **-21.1** 0138 0109
Positive Bank 16:02:37 00527 -40.319 +175.562 +01.3 **+33.2** 0092
0085
TAS 15:58:45 01311 -40.343 +175.611 -06.2 +21.0 **0152**

Figure 6-26. Visor 2000 Printout of PCATD Maximum Flight Variables

Table 6-16. Sample Visor 2000 Printout of PCATD Flight Variables

Time (H:M:S)	Leg No	Altitude (Ft)	Pitch (deg)	Bank (deg)	IAS (kts)
12:56:23	0	1382.0459	7.53284	4.363248	85.17228
12:56:34	1	1420.80096	2.95236	-0.837527	92.27187
12:56:44	2	1479.40349	2.50914	-0.88565	94.40554
12:56:54	3	1512.83202	3.4671	0.74443	98.26286
12:57:04	4	1504.82082	-0.24337	0.725133	104.9448
12:57:14	5	1508.74403	-1.36619	1.410963	108.3921
12:57:24	6	1499.86515	0.04707	1.521249	111.642
12:57:34	7	1494.13174	-1.53837	0.823148	109.5159
12:57:44	8	1361.51096	-4.42447	19.19277	111.2699
12:57:54	9	1256.91004	-2.72571	34.751706	109.569
12:58:04	10	1182.35607	-1.26806	26.739796	104.0261
12:58:14	11	1029.79228	-4.77548	17.290555	113.4491
12:58:24	12	1054.5298	-3.44864	-2.391837	112.4089
12:58:35	13	1050.7277	0.095781	3.172546	114.0566

For the purposes of this study, the Track variable was converted into a Magnetic Heading by subtracting variation. The magnetic variation for the Airport used in the study was set at 21° E. Although the elevation of the Airport 070 Runway was 121 feet for the purposes of this study the overhead-rejoin altitude was rounded off to 1600 feet, circuit height (Above Mean Sea Level) was set to 1100 feet. This would mean that participants could set altitude targets to whole numbers such as 600, 900, 1100, and 1600 feet.

6.5.5 Experimental Procedure

Two senior flight instructors were recruited to define the criterion performance template for the VFR traffic pattern procedure (see Fig. 6-27) and to establish the correct parameters (CAANZ, 2011e).

6.5.5.1 VFR Overhead Rejoin Template

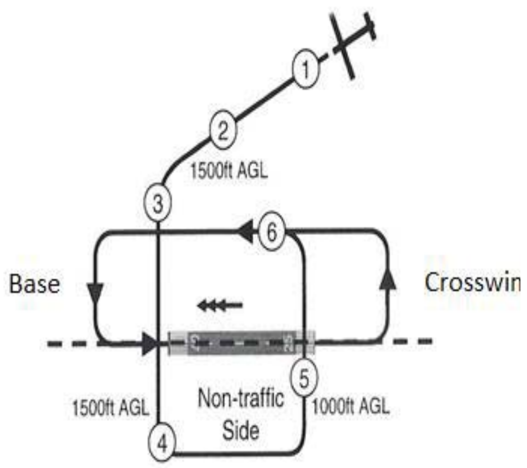


Fig. 6-27. Diagram Key.

1. Enter Traffic Pattern l.
2. Track to keep runway on your
3. left (no less than 1500 feet AGL).
4. Switch Flight Recorder on.
5. After passing over the threshold commence a descent on the non-traffic side to 1000 feet AGL.
6. Cross-upwind threshold at circuit altitude.
7. Join downwind leg.

Figure 6-27. Overhead Rejoin Manoeuvre

The overhead rejoin procedure requires the participant to fly parallel to the runway accurately and this meant the PCATD had to display a minimum of 120 degrees field of view. In addition, the simulator system had to provide sufficient visual display fidelity for the maintenance of a heading appropriate to the particular traffic pattern leg being flown, altitude within 25 ft., and airspeed within 10 knots. Also the criteria for altitude and speed were set at more stringent levels than those suggested by Williams (2001b) to provide a better measure of the PCATD and FTD flight control fidelity.

6.5.5.2 Random Selection

The experimental procedure for the main study was conducted as follows. The ninety three participants were all allocated a consecutive number from 1-93. A PC-based random number generator software program was run on the PCATD. This JavaScript program generated random numbers without replacement from a range of 1-93 numbers (Random Number Generator, 2010). The program generates the first random number and then the second number is randomly generated from the remaining (*n*=92) numbers and so on, until there are 93 random numbers in the sample (Banerjee, 2012).This procedure was repeated several times. Then the participants, based on the random number generation list, were allocated consecutively to three different groups: Control (31), PCATD (31), and FTD (31).

6.5.5.3 Three Group Comparative Study

All participants were pre-tested and post tested on the FTD. The participants randomly selected for the control group received no training on either device. The participants randomly selected for the PCATD group received training on the PCATD and the remaining participants received training on the FTD (see Table 6-17).

Table 6-17. Experimental Procedure

Group	Assignments	Pre Test	Training	Post Test
1	Random (*n*=31)	Familiarisation Lesson / Flight Test in Frasca	Familiarisation Lesson /Three Practice Sessions in PCATD	Flight Test in Frasca TruFlite
2	Random (*n*=31)	Familiarisation Lesson /Flight Test in Frasca	Three Practice Sessions in Frasca TruFlite	Flight Test in Frasca TruFlite
3	Random (*n*=31)	Familiarisation Lesson /Flight Test in Frasca	No Practice Sessions	Flight Test in Frasca TruFlite

The aim was to test all of the participants as efficiently as possible and to minimise the distance they had to travel to a training/testing centre. This was achieved by using Stage 4 SAV2 PCATD and the Frasca TruFlite located at the Massey School of Aviation to train and test Massey Aviation students, and students from the local regional area. The Stage 4 SAV2 PCATD was then disassembled, and relocated to the Ardmore Flying School and reassembled. The Stage 4 PCATD and the Frasca TruFlite owned by the Ardmore Flying School were used to train and test students from the Auckland area. The two Frasca TruFlite FTDS were CAANZ certified devices and were built to a high level of quality, and conformity to international standards. Both FTDs were calibrated to produce a virtually identical flight simulation performance.

All participants were given a 10-15 minute briefing on the VFR overhead rejoin procedure and a demonstration on how it was to be completed. This was followed by a 10-15 minute familiarisation period on the TruFlite FTD. The participants were given a demonstration of the various flight controls on the FTD and were shown how the flight parameters would be recorded.

Then all participants completed the VFR standard overhead rejoin procedure on the FTD. This was the designated pre-test procedure. The flight was recorded on the flight-recording module, which is a component of the Frasca FTD software suite. Analysis of the Frasca flight variable data was the primary evaluation tool and participants were not informed of their results. The researcher ensured that there was only minimal interaction with the participants, and acted in a neutral manner towards each subject. The same script was used to brief each participant to minimise any experimenter bias.

After the pre-test procedure was completed on the Frasca, Group 1 participants were given a 10-15 minute briefing on the operation of the PCATD followed by a 10-15 minute familiarisation session. Then Group 1 participants practiced the VFR standard overhead rejoin procedure with three 10-15 minute training sessions. These sessions were recorded utilising the FltRec software installed on the PCATD. Group 2 participants, after completing the Frasca pretest procedure, completed three 10-15 minute training sessions on the Frasca TruFlite FTD.

Group 3 (Control Group) participants were pre-tested on the Frasca but did not have any practice sessions on either the PCATD or the FTD.

Finally, all the participants were given a short 10-15 minute rest before completing a post-test evaluation of the VFR procedure on the Frasca TruFlite FTD. At the completion of the post-test, the participants were asked a series of questions and their responses were recorded. The experimental procedure was similar to that used in a comparative study of an IFR procedure conducted by McDermott (2004) and Beckman (1998). However, two major modifications were implemented in this study. Instead of using subjective measurement (e.g. flight instructor assessment) to evaluate the student's overall performance, the flight performance data was recorded using the Frasca TruFlite FTD tracking software. The Frasca tracking software can record over 100 unique flight parameters as well as create a visual record of the flight. The PCATD flight parameter data can also be recorded by utilising third party recording software installed on the PCATD instructor station.

The use of flight tracking software to collate the data for evaluation was designed to minimise the effects of experimenter and instructor bias, and strengthen the internal validity of the results. The second modification was to include a third group who were pre-tested and post-tested but did not undergo training in the Frasca TruFlite or the PCATD. The use of a control group was required to provide evidence as to whether training improvement in either device is significantly greater than no training at all.

The VFR overhead rejoin procedure that was evaluated in this study required the utilisation of an FTD or PCATD that could provide a minimum of 120 degrees FOV, (to provide the participants with adequate peripheral views) so that correct entry points and correct spacing could be applied. Each participant was given a briefing on the experimental procedure. This briefing included detailed instruction on the procedure for flying a VFR overhead rejoin pattern on the Frasca TruFlite and in the case of Group 1 the procedure for flying it on the PCATD. On the first stage, the participant entered the traffic pattern at a height of no less or no more than 1500 feet AGL (1600 feet AMSL) and a magnetic heading of 160°-170°.

For the purposes of this study the airfield was deemed to be serviceable, there was no wind, and standard temperature and atmospheric pressure had been set in accordance with ICAO standards (ICAO, 1993). The runway in use was 070°, the circuit was left hand, and there was no traffic on the circuit. The circuit area was defined as the area within a radius of three nautical miles from the airfield reference point.

The second stage of the overhead rejoin procedure was to cross at a ninety degree angle to the runway threshold (on a magnetic heading of 160°), and once established on the non-traffic side of the active runway make a procedural left turn (Rate One) onto a heading of 070°. Then begin a descent from 1500 feet AGL to 1000 feet AGL tracking within 1.0-1.5 nautical miles and parallel to the active runway. This was defined as the upwind or into-wind leg.

On the third stage of the overhead rejoin the participant was directed to ensure that circuit height of 1000 ft. AGL was achieved before the upwind end of the runway threshold had been passed. The participant then chose an appropriate position to turn onto the crosswind leg onto a heading of 340°. A circuit height of 1000 ft. AGL was to be maintained. After passing the runway threshold at 90° to the runway heading and at an appropriate point a turn was initiated onto a heading of 250°. This was defined as the downwind leg**.** At an appropriate distance away from the runway the subject checked for crosswind drift (if any) against selected landmarks and adjusted heading to track parallel to the runway. He/she then performed the appropriate downwind cockpit checks, while holding circuit height. The participant then set the correct power setting, and trimmed the aircraft to maintain an appropriate airspeed that would allow sufficient time to plan for the landing.

The subject then chose an intended touchdown point on the active runway. This touchdown point had to be a sufficient distance into the runway so that an under shoot on approach would still allow a normal round out and touchdown. An overshoot on approach beyond the touchdown point should still allow sufficient runway length to enable the subject to bring the aircraft to a halt. A touchdown point approximately 300- 400 feet from the threshold was a good target to aim for. The subject was instructed to choose another point, approximately 200 feet back from the touchdown point towards the threshold, and this was defined as the aiming point.

At an appropriate distance past the aiming point, the subject initiated a turn onto the base leg on a heading of 160°. The subject then maintained airspeed but reduced power and commenced a descending turn.

The next instructions were to lower the first stage of flap, reduce airspeed, and trim the aircraft. For the purposes of this experiment, a height of 900 ft. AGL was maintained on the base leg. While flying, the base leg the aircraft was set up for the correct approach attitude, correct power and flap setting, trim setting, and required rate of descent.

A descending turn was initiated onto the final approach onto a heading of 070° so that, on completion of the turn, the aircraft was lined up with an extended centreline of the runway. The target altitude for the commencement of the final approach was 600 ft. AGL. Final adjustments to flap, airspeed, and trim settings were required to adjust airspeed to the recommended final approach speed.

Once the aircraft was on a stable final approach, airspeed and the rate of descent was controlled with small movements of the throttle and the flight controls. The subject was required to continue tracking down the final approach, and watch the position and apparent movement of the aiming point relative to the windscreen.

Then at 50 feet or so the subject was required to substantially reduce the rate of descent, reduce thrust to zero, touchdown and roll-out until it was safe to turn off the active runway. If the aiming point appeared to move up the windscreen, the aircraft was too low, and would touchdown before the target. If the aiming point appeared to move down the screen, the subject was too high and would touchdown past the target. If the aiming point appeared to be motionless on the screen, the approach slope was good, and touchdown was close to the target.

6.5.6 Collection of Data–Frasca TruFlite & Stage 4 SAV2 PCATD

A unique aspect of the comparative study was the collection of actual flight variable data from the FTD and PCATD rather than compiling flight-instructor evaluation data.

The Frasca TruFlite uses Graphical Instructor Station software to collect extensive flight variable data including altitude, airspeed and magnetic heading. Similarly, the SAV2 PCATD records identical data with third party software (Visor 2000). In both cases, this data can be stored as a digital recording (which can be replayed in the simulator), comma delimited text, or as hard copy printouts.

6.5.6.1 Standards

The following standard temperature and pressures (as defined by ICAO ISA) were set on the Massey Aviation Frasca TruFlite FTD, Ardmore Flying School Frasca TruFlite FTD, and the SAV2 PCATD (see Table 6-18). Different temperatures and pressures can affect the calculation of altitude and speed by the FTD and PCATD system software. Therefore, for consistency all simulation device internal settings were set to standard temperature and pressure for the comparative study.

Table 6-18. Definition of ICAO International Standard Atmosphere

Standards C	Absolute pressure (kPa)	Relative humidity (%)	Temperature °C
ICAO's ISA	101.325	0	15

Source: (ICAO, 1993)- Manual of the ICAO Standard Atmosphere (extended to 80 kilometres (262 500 feet)), 3rd Edition ICAO, International Civil Aviation Organisation.

6.5.6.2 The National Inter Collegiate Scoring System (NIFA)

The Frasca TruFlite has proprietary software code that drives its simulation engine, which does not enable the use of third party flight variable recording software. Fortunately, it has robust software built into the Graphical Instructor Station that has internal pilot evaluation software based on the USA National Inter Collegiate Flying Association Scoring System.

The Frasca TruFlite does not support the use of third party flight analysis software in its proprietary system. Therefore a replica of NIFA scoring system was developed to rate the performance of the participants who trained on the SAV2 PCATD. The National Inter Collegiate Flying Association sponsors an annual national competition between university and college based flying schools in the United States.

The NIFA Score Module originated as a program used by the National Intercollegiate Flying Association to measure and compare the performance of pilots as each attempted to fly an established flight pattern (Frasca, 2006b). This module records the performance across several flight variables of different pilots, and of the same pilot at different stages of training. It is an objective measure but allows the flight instructor the flexibility of interpreting the scores. Before using the NIFA Score Module, at least one score pattern had to be generated. An overhead rejoin pattern was created by recording the flights undertaken by the senior flight instructors in the initial study. The flight variable output data that was produced from the initial study was collated and analysed. Then using this data as a model of an overhead rejoin pattern an accurate template was created. The template was then coded in the NIFA Score Editor and was used to score the participants overhead rejoin patterns. The template coded in the NIFA Score Editor indicated the optimum value for each flight variable. The NIFA scoring system was calculated using the following criteria (see Table 6-19):

Table 6-19. NIFA Scoring System

Parameter	Criteria for 1 Penalty Point (Weighting)
Pitch, Bank	X degrees deviation per second **(2.0)**
Altitude	X feet deviation per second **(0.1)**
Airspeed	X knots deviation per second **(1.0)**
Heading	X degrees deviation per second **(2.0)**

Source: Frasca (2006). *Operators Manual TruFlite*
(No. OMAN144711 Rev. M). Urbana, Illinois: Frasca

The weightings for each variable ensure that each variable score is in the same order of magnitude.

6.5.6.3 Penalty Point Formula

Initially in the Frasca TruFlite software, the correct flight variables are inserted into the template software. The internal NIFA scoring system scores a participants VFR task performance by attaching penalty points to any deviation of altitude, heading, IAS etc. from the template. Each deviation is calculated and then the weighting is applied and added to the cumulative total of each flight variable and a total cumulative score across all measured flight variables is calculated.

The actual NIFA formula to calculate the number of penalty points for each variable is:

NIFA Score = Absolute Value (ABS) - (Actual Value-Pattern Value) x Weights per second. ……………………………………………………………..….....Equation (6-1)

Example 1: Altitude

Pattern value =2000 ft.

Actual value = 2100 ft.

Weight = 0.1

This value will score Penalty = 0.1 x (2100-2000) = 10 penalty points per second.

Example 2: Heading

Pattern value =160° magnetic

Actual value = 170° magnetic

Weight = 2

This value will score Penalty = 2 x (170-160) = 20 penalty points per second.

6.5.6.4 NIFA Template

The NIFA template for the Overhead Rejoin Pattern used in the comparative study consisted of 13 legs:

- Leg 1 – Entry into pattern (Heading 170);
- Leg 2 – Cross over 070 Runway Threshold (Heading 160);
- Leg 3 – Procedural Turn onto Upwind leg;
- Leg 4 – Upwind Leg (Heading 070);
- Leg 5 - Procedural Turn onto Crosswind leg;
- Leg 6 – Crosswind Leg (Heading 340);
- Leg 7 - Procedural Turn onto Downwind Leg;
- Leg 8 – Downwind Leg (Heading 250);
- Leg 9 - Procedural Turn onto Base Leg;
- Leg 10 – Base Leg (Heading 160);
- Leg 11 - Procedural Turn onto Final Approach;
- Leg 12 – Final Approach (Heading 070);
- Leg 13 – Final Approach & Landing (Heading 070).

The NIFA Score Pattern Master values were based on an analysis of the flight instructor performance of the overhead rejoin manoeuvre executed in the initial study. Due to the varied completion-times for the overhead rejoin manoeuvre, one scoring template could not adequately cover all the different completion times for the Overhead Rejoin Manoeuvre.

For example, a participant who extended the downwind leg or the upwind leg would accrue more penalty points if only one template was used. After discussions with designated flight instructors, they agreed that a participant should not be adversely penalised for varying time intervals when completing the overhead rejoin pattern. Therefore, several templates were produced with varying time intervals for each leg. When a participant's recorded flight was replayed, the template with the best matching template in terms of time per leg was used for scoring that particular flight. This provided a much more accurate assessment of the penalty points per second accrued by the participant for their particular flight.

6.5.6.5 Flight Variables

A number of critical flight variables had to be recorded such as airspeed, bank angle, pitch, altitude, and magnetic heading. However these flight variables can include different measures of airspeed all of which can be calculated by the FTD and PCATD system software.

Airspeed

A pilot is mainly concerned with three measures of airspeed. These are true airspeed (TAS) indicated airspeed (IAS), and groundspeed (GS). There are two other types of airspeed, calibrated airspeed (CAS) and equivalent airspeed (EAS) but these measures were not used, as they are more applicable to aircraft travelling at high speeds and high altitudes. Nevertheless, it is essential to know the difference between the different measures of airspeed. In the comparative study, AIS was the most relevant measure because it is AIS which is specified in the pilot's aircraft operations manual and directly relates to flight performance values such as stall speed (Transport Canada, 1994). IAS values recorded from the flight instructor sorties were averaged, and the values were inserted into the appropriate legs of the overhead rejoin template.

Indicated Airspeed (IAS)

In terms of the experimental procedure, this was the speed, which was measured. It was the speed that was displayed on the airspeed indicator in the Frasca TruFlite simulator, and the instrument panel of the PCATD. In the PCATD, the airspeed indicator was capable of displaying IAS or TAS by setting a software code. For the purposes of this experiment, the IAS was selected in the PCATD software, (Aircraft - Realism Settings - Display Indicated Airspeed). In the Frasca TruFlite, the indicated airspeed variable output was selected in the Parameter Plot Module and displayed on the instrument panel. IAS is the airspeed variable that the participant referenced while completing the VFR overhead rejoins manoeuvre. This speed determines if the aircraft flies or not. Landing speeds, and minimum maneuvering speeds are always displayed as indicated airspeeds and that is why indicated air speed is the primary reference (EASA, 2003).

Calibrated Airspeed (CAS)/Equivalent Airspeed (EAS)

Calibrated airspeed (CAS) is the speed shown by an airspeed indicator after corrections have been made for instrument error and position error. At high speeds and altitudes, calibrated airspeed is further corrected for compressibility errors and is defined as equivalent airspeed (EAS). EAS compensates for the fact that at higher airspeeds and altitudes the compressibility of the air can cause the airspeed indicator to read erroneously high (EASA, 2003).

True Airspeed (TAS)/Ground Speed (GS)

TAS is the main speed variable used in flight navigation. When there is no wind, TAS will be the same as groundspeed (GS) and can be used to calculate how long a flight will take. It is also the speed, which is filed in an official flight plan. TAS is IAS, corrected for changes in altitude and temperature; as the temperature or altitude increases, the air density will decrease and this will cause the indicated airspeed to read lower than the true airspeed. At sea level on a 15°C day, IAS will be the same as TAS. As altitude increases, the difference between TAS and IAS will increase. At 10,000 ft. and -5°C, 250 knots IAS will convert to 290 knots TAS. At 20,000 ft. and -25C, 250 knot IAS will convert to 335 knots TAS. The difference between TAS and IAS can be quite large at high altitudes. A good approximation that pilots use is to calculate the difference between IAS and TAS as a 2% difference per 1000 ft. increase in altitude (EASA, 2003).

Ground speed is the speed of an aircraft relative to the ground, and is corrected for a tailwind or headwind component (see Equation 6-2).

Bank Angle

A number of assumptions and approximations were made to calculate the correct angle of bank for the template. These calculated values were then compared to actual values produced when the experienced flight instructors flew the overhead rejoin pattern in the initial study. The difference between the calculated and observed values was negligible. Each turn required in the overhead rejoin was standardised as a rate one turn. A standard turn for light aircraft is defined as a 3° per second turn, which therefore completes a dull 360° turn in 2 minutes. This is known as a 2-minute turn, or rate one turn (= 180°/minute). In the overhead rejoin all turns were 90° turns so the time allocated in the template to complete the turn was 30 seconds. However, the correct angle of bank is then calculated for the relevant speed of the aircraft. To calculate the correct bank angle two separate calculations had to be made. The first formula (see Equation 6-2) converts Indicated Air Speed to True Air Speed. The second formula (see Equation.6-3) calculates the angle of bank (AOB) for a rate one turn (2 minutes for a 360° rotation):

TAS= [(IAS x 2%) • (ALT/1000)] + IAS. …………………………………Equation (6-2)

AOB = arc tan ((2 x Π x TAS x 0.51444) / (9.81m/s^2 x 120 secs)) ………. Equation (6-3)

<u>Example 1</u>

TAS= [(IAS x 2%) • (ALT/1000)] + IAS

97.09 = ((95x0.02) * (1100/1000)) + 95

<u>Example 2</u>

AOB =Degrees (Arc tan ((2*97*PI*0.51444)/ (9.81*120)))

AOB = 14.90670729

However, after some discussion with the flight instructors it was decided to use a simpler formula (see Equation 6-4). This formula was incorporated into the template because the pilot trainees used it to calculate (by mental dead reckoning) the correct bank angle as they completed the overhead rejoin maneuver.

Angle of Bank ≈ (TAS /10) +7 ………………………………………….. Equation (6-4)

Example 3

AOB = 97/10 +7

= 16.7 ≈ 17 degrees

This simplified formula provided an accurate approximation with a less than 10% relative error between the airspeed ranges of 110-550 knots. For light single engine aircraft, there is little difference between IAS and TAS at the average height (1500 ft. AGL) of the overhead rejoin manoeuvre. In addition, to minimise the variation between IAS and TAS the Frasca TruFlite FTD and the PCATD environmental variables were set at STP's with zero wind speed.

Pitch Values

The pitch values of the instructor flight's template were averaged and the template value of two degrees pitch down (i.e. -2 degrees) was inserted into the overhead rejoin template in the appropriate legs.

Magnetic Heading

The magnetic heading values of the overhead rejoin pattern were based on a left hand circuit pattern for Palmerston North airport. These values were inserted into each of the thirteen legs of the overhead rejoin template.

Total Score

The NIFA Scoring Module also provided a total cumulative penalty score for the following flight variables:

1. Pitch;
2. Bank;
3. Altitude;
4. IAS;
5. Magnetic Heading;

Glideslope

The calculation of glideslope on the final approach had to be taken from graphical data. The Frasca TruFlite parameter plot module provided a graphical printout of the three variables Altitude, Magnetic Heading, and Indicated Airspeed. A transparent overlay with a measuring grid was used to measure these variables. The Parameter plot module printout for the Ardmore TruFlite Frasca was on a different time scale than the Massey TruFlite Frasca. Therefore, two different overlay grids had to be used. Glideslope was calculated by dividing altitude (ft.) by horizontal distance (ft.). The calculation of glideslope was completed in three steps (See Fig. 6-28, Equation 6-5):

1. The average IAS in knots on the approach path was converted to TAS;
2. The TAS was then converted from nautical miles per hour (nm/hr.) to feet per second (fps);
3. The horizontal distance was calculated by multiplying the TAS (=groundspeed, no wind) by the time interval (TI) in seconds from top of approach to touchdown.

Glideslope = (ATAN (1/ (((TI*15)/3600)*((IAS*0.02)*(ALT/1000) +IAS))*6080)*

ALT))*180/PI -Excel Formula ……………………………………………...Equation (6-5)

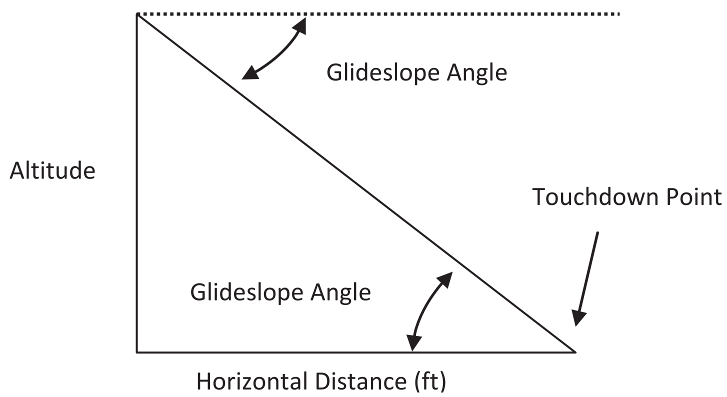


Figure 6-28. Diagram of Glideslope Angle

6.5.6.6 Overhead Rejoin Pattern Assessment FTD

The overhead rejoin pattern (shape) was qualitatively assessed by two experienced flight instructors (one was an A Category flight instructor[25]). They both had over 1000 hours of instructional experience on single and twin-engine aircraft, and more than 250 hours instructional experience on the Frasca TruFlite FTD. The student participants had their Frasca TruFlite FTD test recorded and a printout of the overhead pattern was randomly assigned to the flight instructors for evaluation. After some discussion with the two flight instructors, they recommended that they rate the overhead rejoin pattern on a five point Likert scale (see Table 6-20). A larger scale would have made it difficult for them to discriminate accurately between overhead rejoin printouts. The flight instructors then rated the accuracy of the pattern (shape). This was the only task performance variable that was evaluated rated flight instructors as the remaining flight variables were recorded digitally and then analysed statistically.

Table 6-20. Overhead Rejoin Pattern Scale

Score	Standard Overhead Rejoin Pattern
1	No deviation
2	Minimal deviation
3	Minor deviation
4	Major deviation
5	Extreme deviation

6.5.6.7 Overhead Rejoin Pattern Assessment PCATD

The second comparative study involved a comparison of two pilot trainee groups with different levels of aviation experience and their VFR overhead rejoin task performance on the Stage 4 SAV2 PCATD. For this second study, there was a limitation in the recording and printing of the overhead pattern rejoin pattern. The PCATD recording software could

[25] An applicant for a CAT A Instructor rating requires a minimum of 1250 hours total flight experience and 750 hours instructional time (CAANZ, 2011c)

only record the aircraft variables once every 10 seconds (Visor 2000) Therefore, the aircraft position could only be recorded once every ten seconds. The resolution and accuracy of the overhead rejoin printout was not accurate enough for the flight instructors to evaluate correctly. Therefore, this particular VFR task measure had to be excluded from the second comparative study.

6.5.7 Initial Trial (Pilot Study)

An initial study was undertaken whereby ten participants (four flight instructors, six flight trainees) were selected to undertake the quasi transfer study using the SAV2 PCATD and the Frasca TruFlite FTD. The aim of the initial study was to ascertain if the experimental methodology or experimental apparatus had any issues or problems that had to be resolved. No control group was used. Participants were pre-tested in the FTD, trained on the PCATD and post-tested on the FTD. Apart from the heuristic evaluation of the PCATD completed by the participants, flight performance data from the initial study was not subjected to analysis. Because of the small number of participants in the initial study, lack of random selection, and no control group, the task performance results were not recorded.

6.5.7.1 Initial Pilot Study Data Outputs

For the initial study, a profile overhead-rejoin manoeuvre was generated on the Frasca TruFlite FTD by two experienced flight instructors. This profile was recorded and used as a guide for the development of a template for a standard overhead rejoin manoeuvre (see Section 6.5.5.1). This template of the standard overhead rejoin manoeuvre was then used as the baseline for the performance of the overhead rejoin manoeuvre. Three modules in the Frasca TruFlite FTD GISt (Map Display, Parameter Display, and NIFA Score) were used to print out the correct profiles.

6.5.7.2 Frasca TruFlite Map Display Module Printout

The Map Display module printout displays the correct overhead rejoin pattern centred on Palmerston North Airport (see Fig. 6-29). This pattern was flown by an experienced flight instructor. The circuit is a left hand circuit with a final approach onto runway 070.

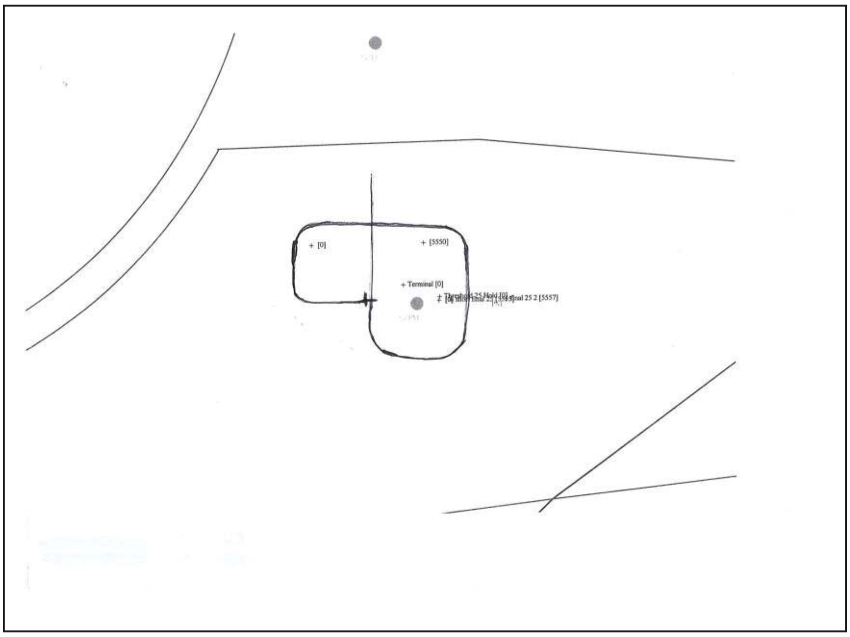


Figure 6-29. Frasca Map Display Module Printout

6.5.7.3 Frasca TruFlite Parameter Plotting Module Printout

The variables for the instructor profile were recorded through the Parameter Plotting Module and were printed out (see Fig. 6-30).

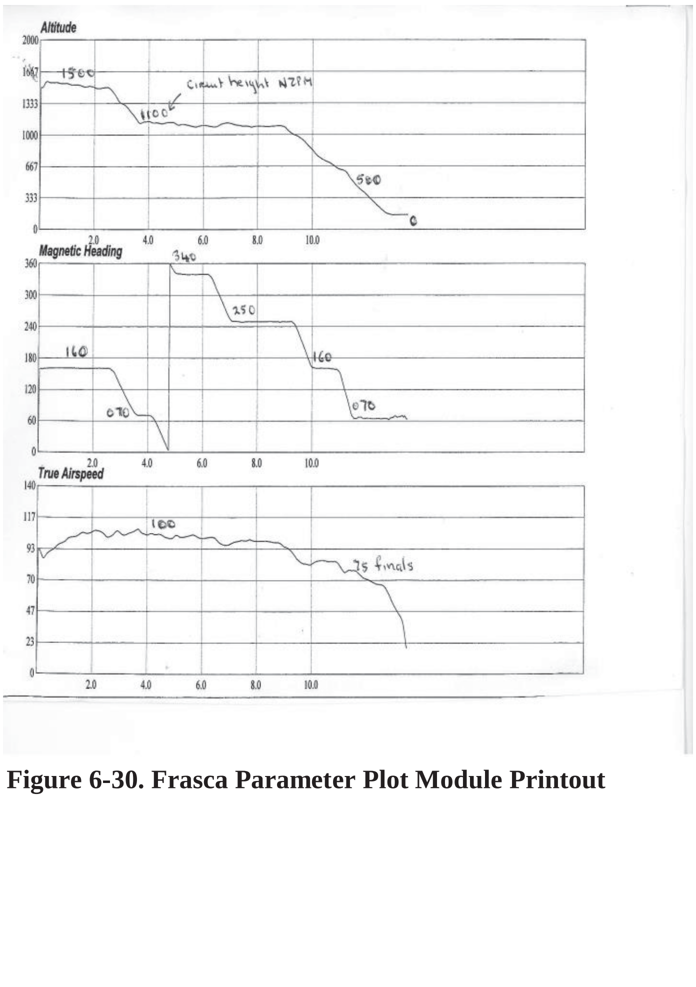


Figure 6-30. Frasca Parameter Plot Module Printout

6.5.7.4 Frasca TruFlite NIFA Scoring Module Printout

The participant's performance across the dependent variables was recorded in the Frasca TruFlite and the data was output in numerical form (see Fig. 6-31). The flight recording can be replayed in real time and different variables can then be measured. Because of the very small number of participants in the initial trial, the results of VFR task performance were not statistically valid. However, the results did indicate that the group of participants who trained on the PCATD and on the FTD demonstrated greater improvement in performing the standard overhead rejoin manoeuvre than the control group. Also participants had no difficulty with understanding and operating the PCATDs and FTD in the familiarisation lessons, training sessions, and pre-test and post-test sessions. The Scoring Module Data was inserted into a spreadsheet so that an error rating per second could be calculated (see Table 6-21).

GISt NIFA Score Results: PHD7_00master

	Time	Pitch	Bank	Altitude	Vertical Speed	Airspeed	Rate of Turn	Slip	Heading	Leg Score
Leg 1	60	412	164	162	0	729	0	0	803	2270
Leg 2	20	107	41	303	0	179	0	0	66	696
Leg 3	30	152	617	881	0	255	0	0		1905
Leg 4	25	139	433	832	0	198	0	0	625	2227
Leg 5	30	101	705	967	0	282	0	0		2055
Leg 6	30	67	505	815	0	266	0	0	839	2492
Leg 7	30	166	1002	421	0	235	0	0		1824
Leg 8	60	351	894	189	0	611	0	0	2461	4506
Leg 9	30	132	979	244	0	318	0	0		1673
Leg 10	25	113	695	365	0	84	0	0	3380	4637
Leg 11	30	327	652	1092	0	208	0	0		2279
Leg 12	25	289	712	626	0	251	0	0	1502	3380
Leg 13	25	186	163	103	0	263	0	0	154	869
Item Total		2542	7562	7000	0	3879	0	0	9830	**30813**

School:
Instructor:
Student: [redacted]

Date: 04-Aug-09
Time: 10:18 PM

Figure 6-31. Frasca TruFlite NIFA Scoring Module Printout

Table 6-21. NIFA Error Rating Score per Second

Total Score	ID	Pitch	Bank	Altitude	IAS	Heading
34500.00	Sub2_FTD_pretest raw	3548.00	7742.00	7090.00	6571.00	9549.00
95.83	Sub2__FTD_pretest per sec	9.86	21.51	19.69	18.25	26.53
13562.00	Sub2__FTD_post-test raw	2560.00	2448.00	3438.00	2705.00	2411.00
36.65	Sub2_FTD_post-test per sec	6.92	6.62	9.29	7.31	6.52
59.18	Sub2 Gain Score	2.94	14.89	10.40	10.94	20.01

6.5.7.5 Initial Trial (Pilot Study) Participants

For the initial study, ten participants were selected purposively[26]. These were flight instructors and student pilots who were working and studying locally and could be easily recruited for the initial study. A range of flight experience was achieved by including junior (C Category) and senior flight instructors (B Category), students with a CPL or PPL, and ab-initio students in the group (see Table 6-22). The aim was to test pilots who had a range of flight experience in the initial study, to see if any problems might arise which might adversely affect the major study. The demographic composition of the ten pilots that completed the evaluation was as follows:

1. The pilots were male;
2. The pilots age range was between 20-38 years;
3. The total aircraft flight hours of each pilot ranged from 50-1000 hours with a mean of 331 hours (Median 200 hours);

[26] Purposive Sampling is where the researcher chooses the sample based on whom they think would be appropriate for the study. This sampling technique is used primarily when there are a limited number of participants that have expertise in the area being researched (Babbie, 2001).

4. Four pilots were flight instructors, two had a CPL, two had a PPL, and two were ab-initio students.

Table 6-22. Initial Study Pilots – Aircraft, FTD & PCATD Training Experience

Total Flight Hours Experience	VFR Flight Hours Experience	Recent Flight Hours Experience (Previous Month)	PCATD Hours Experience Total	FTD Hours Experience
0 (50 hours<)	0 (50 hours <)	3 (10 hours <)	2 (0.5 hours<)	1 (0.5 hours<)
5 (50-250 hours)	5 (50-250 hours)	5 (10-30 hours)	7 (0.5-20 hours)	4 (0.5-20 hours)
5 (>250 hours)	5 (>250 hours)	2 (>30 hours)	1 (>20 hours)	5 (>20 hours)

6.5.7.6 Heuristic Evaluation

The participants in the initial study were asked to provide a heuristic evaluation of the SAV2 PCATD and its suitability as a measurement tool for the major study: A Likert scale was used that provided a range of responses that measured the respondent's intensity of feeling concerning the statement. A decision was made to adopt a five point scale which was used in previous studies (Johnson & Stewart II, 2005; Stewart, 2001). The response/evaluation categories were *Strongly Disagree*, *Moderately Disagree*, *Neutral*, *Moderately Agree*, and *Strongly Agree*. The evaluation consisted of the following statements:

1. The physical fidelity of the flight controls was at a high enough level in terms of accuracy and feedback response to complete the VFR Overhead Rejoin Procedure.

Three participants Moderately Disagree, three were Neutral, and three Moderately Agree.

The feedback from the participants was that the PCATD was more difficult to fly. The flight controls were more sensitive and they did not match the fidelity of the servo driven flight controls in the FTD. This meant participants had to concentrate more, and execute manoeuvres with increased fine motor control. They did agree that this might not be a disadvantage in terms of training as it made them focus more on their flight control inputs and react more quickly to the corresponding effect on the visual cues.

2. The resolution of the NZ terrain depicted in the PCATD was accurate enough to complete the VFR Overhead Rejoin Procedure

One participant Moderately Disagrees, three were Neutral, and six Moderately Agree.

The majority of the participants found the depiction of terrain in the PCATD superior to that of the FTD. Due to the relatively high control fidelity of the Frasca TruFlite, participants found it easier to maintain the correct magnetic heading and airspeed. However, altitude control was more difficult to achieve. One of the reasons for this was the generic terrain database of the Frasca which did not contain any elevation information (i.e. no hills or valleys are depicted). This did make it difficult for the participants to find an external horizon to assist with flying straight and level.

3. The flight model characteristics of the Piper Cherokee developed for the SAV2 PCATD match the real training aircraft accurately.

Three participants Moderately Disagree, three were Neutral, and four Moderately Agree.

There was a mixed response to the evaluation of the flight characteristics of the PCATD. The flight model did accurately reflect the Piper Cherokee performance characteristics (e.g. rate of climb, cruise speed, and rate of descent). However, participants did comment on the overall feel of the flight model, which they felt still needed improvement. This evaluation was susceptible to personal bias and was reflected by the fact that the participants were also critical of the accuracy of the FTD flight model.

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to complete the VFR Overhead Rejoin Procedure.

Two participants Moderately Disagree, three were Neutral, and five Moderately Agree.

All of the participants found the external cockpit display of the PCATD equal in quality to the FTD external display. It was more than adequate to provide the necessary visual cues.

5. The instrument panel depicted in the PCATD panel was realistic enough to complete the VFR Overhead Rejoin Procedure. Procedure.
Three participants Moderately Disagree, two were Neutral, and five Moderately Agree.

The participants only required the standard six-pack of flight gauges to complete the VFR overhead exercise. The only criticism was the digital gauges depicted on the instrument panel screen were smaller than real gauges. An adjustment was made to the instrument panel to include a six-pack of gauges and gauge size was increased to eighty per cent of life size.

6. The instructions were concise enough for you to complete the VFR Overhead-Rejoin Procedure on the SAV2 PCATD.
Ten participants Strongly Agree.

All participants were satisfied with the instructions for completing the experiment.

7. Your performance in the FTD improved after completing the VFR training procedures on the SAV2 PCATD.
Two participants Moderately Disagree, four were Neutral, three Moderately Agree, and one Strongly Agrees.

The majority of participants felt that training in the PCATD was beneficial and improved their performance in the FTD. Although not statistically significant most of the PCATD trained participants performed better in the post-test on the FTD when compared to their pre-test results.

8. What other issues concerning the PCATD did you notice while performing the evaluation (Problems, concerns, improvements, limitations, etc.)?

Using computer keyboards for some system functions did reduce the psychological fidelity and sense of immersiveness. This issue would have to be addressed in the next PCATD project.

6.5.7.7 Conclusion

Apart from the adjustment to the control-panel instrument-gauge size, the PCATD was considered to be at a level of fidelity that would be sufficient to complete training on the VFR overhead rejoin procedure. Most of the participants that trained on the PCATD and the FTD found the training sessions beneficial and they believed it helped them to improve their VFR performance in the Frasca TruFlite post-test exercise. On the strength of those results and feedback received from the participants in the initial study, the decision was made to proceed with the major study.

6.5.8 Results of Stage 4 PCATD Comparative Study

The major study was comprised of two parts. The first part of the study compared the effectiveness of the SAV2 PCATD and a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation. The second part of the study compared the effectiveness of the Stage 4 SAV2 PCATD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation between two pilot trainee groups with different aviation experience levels and in different geographical locations. Part 1 was designed using a quasi-transfer methodology where VFR task performance was tested on a CAANZ certified FTD as this device was a high fidelity replica of the real aircraft. In the second part of the study, two groups of participants were purposively chosen by their aviation experience, and their VFR task performance solely on the Stage 4 SAV2 PCATD was compared. Flight variables were recorded by the PCATD software system and the participants' performance was rated using the NIFA scoring system and calculated deviation. VFR task performance was compared between two groups of participants to establish if training performance on the Stage 4 SAV2 PCATD was affected by differing levels of flight training experience, different locations, and different flight training regimes.

6.5.8.1 Research Question 1

Is the Stage 4 SAV2 PCATD as effective as a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation?

The purpose of this study was to ascertain if the Stage 4 PCATD was as effective as a CAANZ certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation. Testing was completed solely on the FRASCA TruFlite in this first study but the PCATD was used for testing in the second study.

6.5.8.2 Aviation Experience Levels

Five demographic factors were obtained from the questionnaire that was administered at the beginning of the research project: Total Flight Time, VFR Flight Time, FTD Time, PCATD Time, and Recent Flight Time (see Appendix N). The descriptive statistics are listed in Table 6-23. Also in Group 1 (PCATD), 10 participants had a PPL. In Group 2 (FTD), 7 participants had a PPL and in Group 3 (Control) 14 participants had a PPL. Random assignment of participants to one of the three groups was initiated and no participants withdrew prematurely from the study. All groups were similar in that they had very little PCATD experience (9 pilots had less than twenty hours) but had a reasonable level of experience with FTDs (5 pilots had more than 20 hours).

Table 6-23. Comparative Means & SD's in Aviation Experience of Three Groups

Aviation Experience (Hrs)	Group ID	No.	Mean	SD
PCATD Time	1	31	0.55	2.69
	2	31	0.82	2.43
	3	31	0.98	3.59
FTD Time	1	31	3.11	7.49
	2	31	5.08	18.72
	3	31	8.95	25.31
Total Flight Time	1	31	213.36	785.36
	2	31	82.82	164.45
	3	31	194.67	415.25
VFR Flight Time	1	31	207.38	777.45
	2	31	68.05	111.51
	3	31	179.77	367.13
Recent Flight Time	1	31	8.55	13.80
	2	31	6.68	9.29
	3	31	7.15	9.16

A Means Plot of Aviation Experience (see Fig. 6-32) indicated no significant difference in the means of the aviation experience variable data between the three groups. A Levene's test of Homogeneity of Variance did not reveal any issue regarding homogeneity. A one-way between subjects ANOVA was conducted to establish if there was any significant difference in the aviation experience of the participants randomly assigned to one of three different groups (see Table 6-24). No evidence was found of a significant main effect for any of the aviation experience variables between groups. These results indicate the three groups are homogenous in terms of aviation experience and therefore previous aviation flight experience should not influence VFR task performance on the FTD.

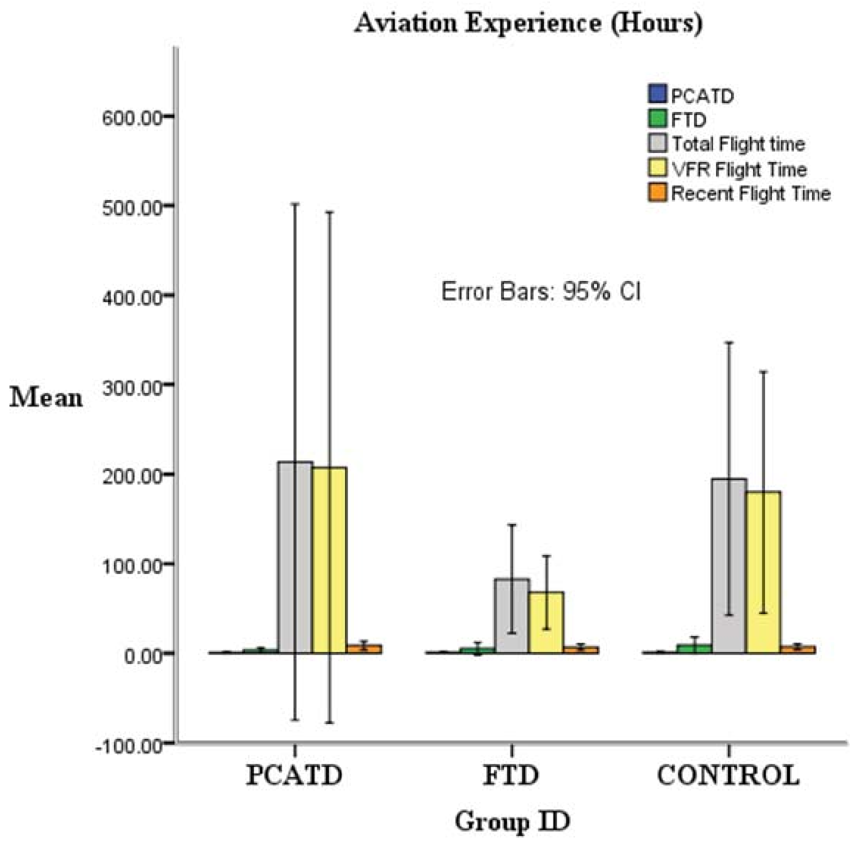


Figure 6-32. Aviation Experience Means Plot Graph

Table 6-24. ANOVA Results-Aviation Experience

Aviation Experience (Hrs)	*df*	*df2*	*F*	*Sig.*
PCATD Time	2	90	.173	.84
FTD Time	2	90	.785	.46
Total Flight Time	2	90	.568	.57
VFR Flight Time	2	90	.673	.51
Recent Flight Time	2	90	.242	.71

6.5.8.3 FTD Pre-Test & Post-Test Scores

The descriptive statistics for the three groups Pre-test and Post-test scores are listed in Table 6-25.

Table 6-25. Comparative Statistics of FTD Pre-Test Scores of Three Groups

Group ID	GP1 PCATD) (*n* =31)		GP2 FTD (*n*=31)		GP3 Control (n=31)	
	Mean	SD	Mean	SD	Mean	SD
Pre-Test Pitch	6.68	2.06	6.09	1.90	6.04	2.29
Pre-Test Bank	15.30	3.96	15.08	3.81	13.67	3.83
Pre-Test Altitude	13.14	5.94	15.15	7.98	13.62	6.69
Pre-Test IAS	11.53	4.27	10.67	4.76	10.72	4.03
Pre-Test Heading	18.95	12.27	20.97	10.73	18.67	10.87
Pre-Test Total	65.61	21.11	67.97	22.17	62.74	21.019
Pre-Test Glide	3.96	1.19	4.00	.98	3.78	1.40
Pre-Test Pattern	2.48	0.81	2.52	0.89	2.58	0.96
Post-Test Pitch	5.56	1.74	5.06	1.58	6.20	2.52
Post-Test Bank	11.66	3.04	12.51	3.91	13.54	3.78
Post-Test Altitude	10.22	3.52	10.70	4.53	11.42	4.81
Post-Test IAS	9.91	3.06	8.46	2.83	10.47	4.22
Post-Test Heading	11.86	7.25	12.47	7.25	15.78	11.62
Post-Test Total	49.22	13.14	49.20	15.56	57.41	21.98
Post-Test Glide	3.92	1.03	4.14	1.10	4.00	1.45
Post-Test Pattern	2.23	.88	2.06	.68	2.32	.79

A 3x2 mixed model ANOVA was used to analyse the performance of a VFR Overhead Rejoin manoeuvre by three groups of pilots who were tested in a high fidelity FTD. Initially participants were pre-tested on a FTD. Then they were trained on either a PCATD or FTD, or not trained at all before being post-tested on the FTD. The participants VFR task performance was measured through eight dependent variables, six of the variables (Pitch, Bank, Altitude, Indicated Air Speed, Magnetic Heading, and Total Score) were rated using the NIFA scoring system. The glide variable score was calculated by measuring graphical landing approach data and scoring the deviations from a 3° standard glide slope template. The Overhead Rejoin Pattern was rated for accuracy by two senior flight instructors using categorical evaluations.

A comparison using a mixed model ANOVA was made between the Pre-test score and the Post-test score performance to ascertain if there was a difference in test performance scores on the FTD between the three groups. Also, differences in pre-test or post-test performance scores between the groups were measured by ANOVA between subjects effects. This was to ensure that differences in FTD training experience, overall aviation experience, or maturation effects did not influence performance change scores between groups. If a significant difference was found within the three groups then a post hoc test was applied. The simplest Post-hoc test, the Fisher Least Significant Difference (LSD) was chosen for this study. The Fisher LSD test is based on the assumption that if ANOVA is conducted and is significant, the null hypothesis is incorrect. Post-hoc analyses are used to search for patterns or relationships between subgroups of sampled populations that would otherwise remain undetected. Post-hoc tests limit the probability that significant effects that have been discovered between subgroups of a population do not actually exist. Post-hoc testing also assists with preventative control of Type I Errors (Jaccard, Becker, & Wood, 1984).

The statistical analysis was applied to the following flight performance variables:

1. Pitch Variable;
2. Bank Variable;
3. Altitude Variable;
4. Indicated Airspeed;

5. Heading Variable;
6. Total Variable Score;
7. Glideslope Variable;
8. Overhead Rejoin Pattern.

Pitch Variable

A mixed model ANOVA was conducted to compare three groups of participants on Pitch performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90) = 11.07$, $p=.001$, $\eta 2 = .11$. There was no evidence of a difference between groups, $F(2, 90) = .947$, $p = .392$. However there was evidence of an interaction between group training and pitch performance, $F(2, 90) = 4.191$, $p = .018$, $\eta 2 = .09$, which indicates that the groups did have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-33, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

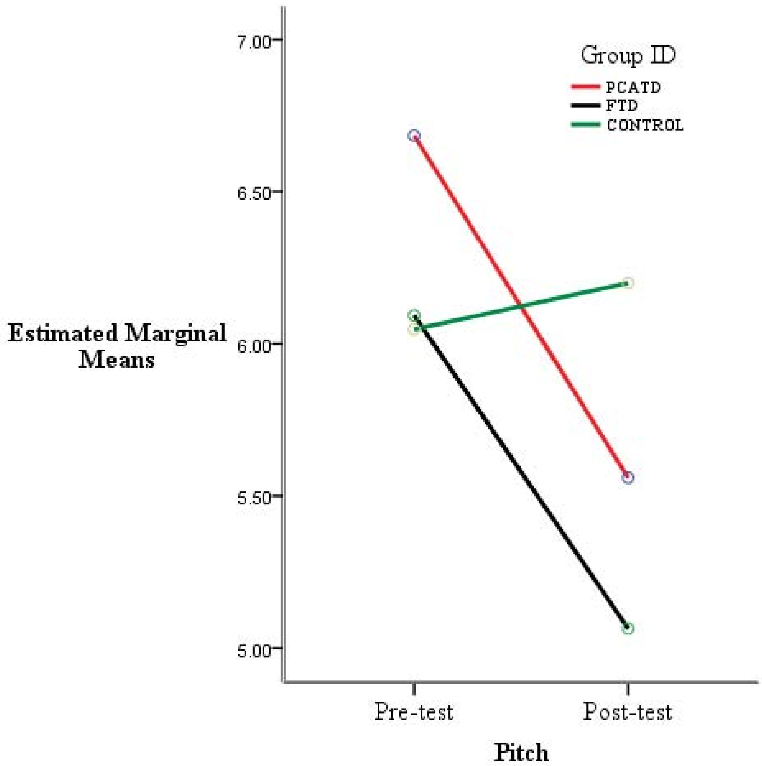


Figure 6-33. Means Plot Pitch Performance

Post –Hoc Analysis of Interaction between Group and Pitch Performance

Post hoc analyses using the Least Significant Difference (LSD) post hoc criterion for significance indicated that there was significantly less improvement in the Pre-test vs. Post-test change score for pitch performance in the control group (M=-0.15, SD=1.96) when compared to the FTD group (M=1.03, SD =1.78), and the PCATD group (M=1.12, SD=2.05) at the $p < .05$ significance level. However, there was no significant difference in change score for pitch performance between the PCATD group and the FTD group (see Fig. 6-34).

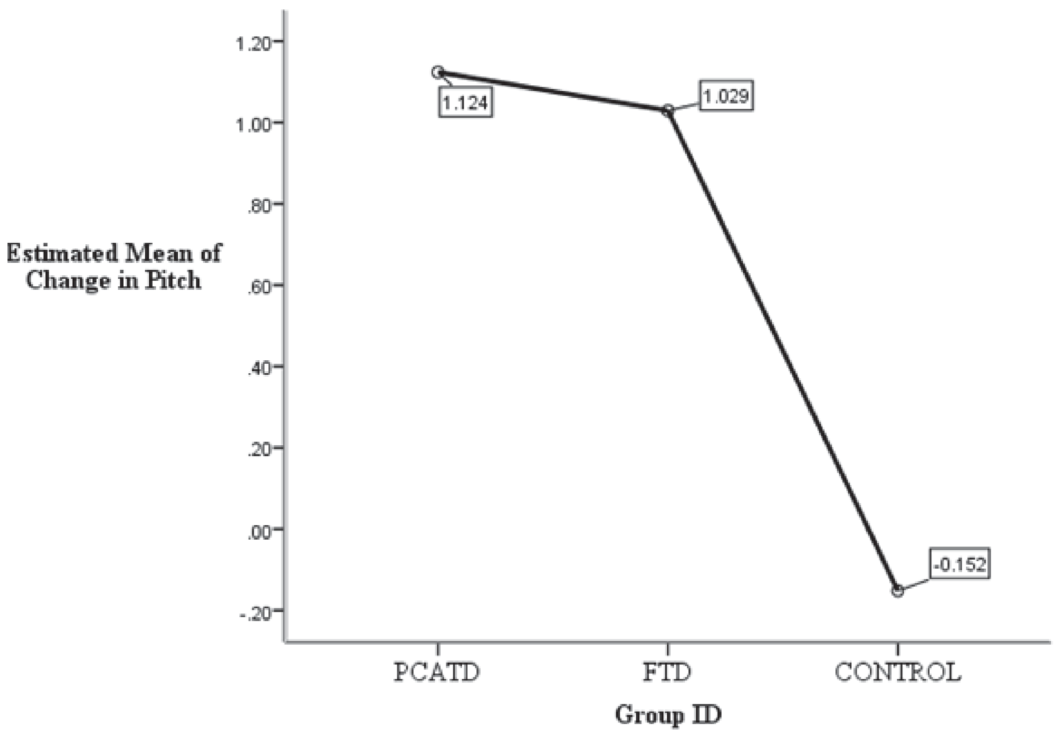


Figure 6-34. Post Hoc Pitch Change Scores Means Plot

Bank Variable

A 3x2 mixed model ANOVA was conducted to compare three groups of participants on Bank performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90)= 20.198$, $p=.000$, $\eta 2 = .18$. There was no evidence of a difference between groups, $F(2, 90) =.087$, $p =.916$. However, there was evidence of an interaction between group training and bank performance, $F(2, 90) =4.814$, $p =.010$, $\eta 2 = .10$, which indicates that the groups did have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-35, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

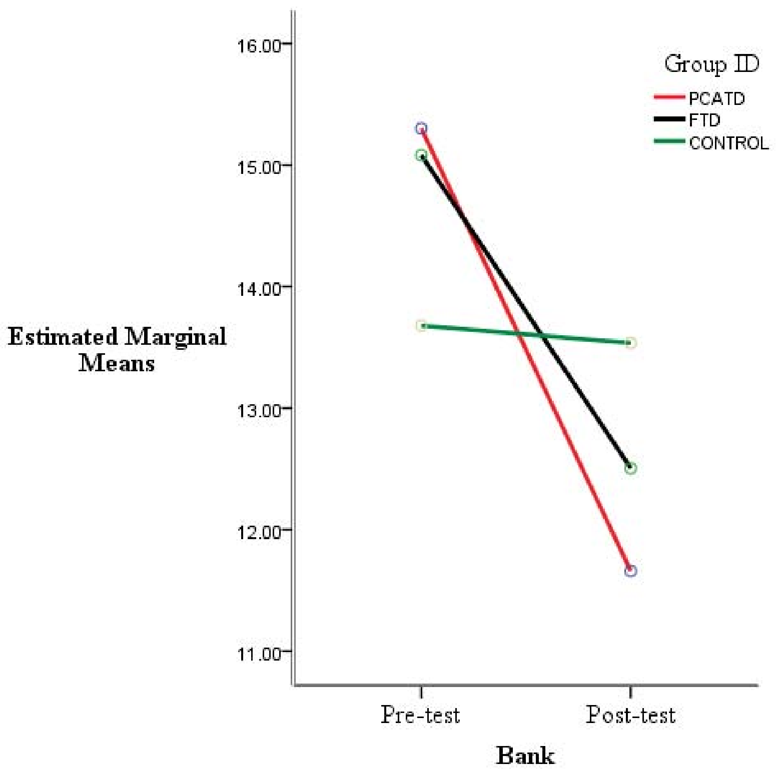


Figure 6-35. Means Plot Bank Performance

Post –Hoc Analysis of Interaction between Group and Bank Performance

Post hoc analyses using the Least Significant Difference (LSD) post hoc criterion for significance indicated that there was significantly less improvement in change score for Bank performance in the control group (M=0.14, SD=4.59) when compared to the FTD group (M=2.58, SD =4.48) and the PCATD group (M=3.64, SD =4.57) at the $p < .05$ significance level. However, there was no significant difference in change score for Bank performance between the PCATD group and the FTD group (see Fig. 6-36).

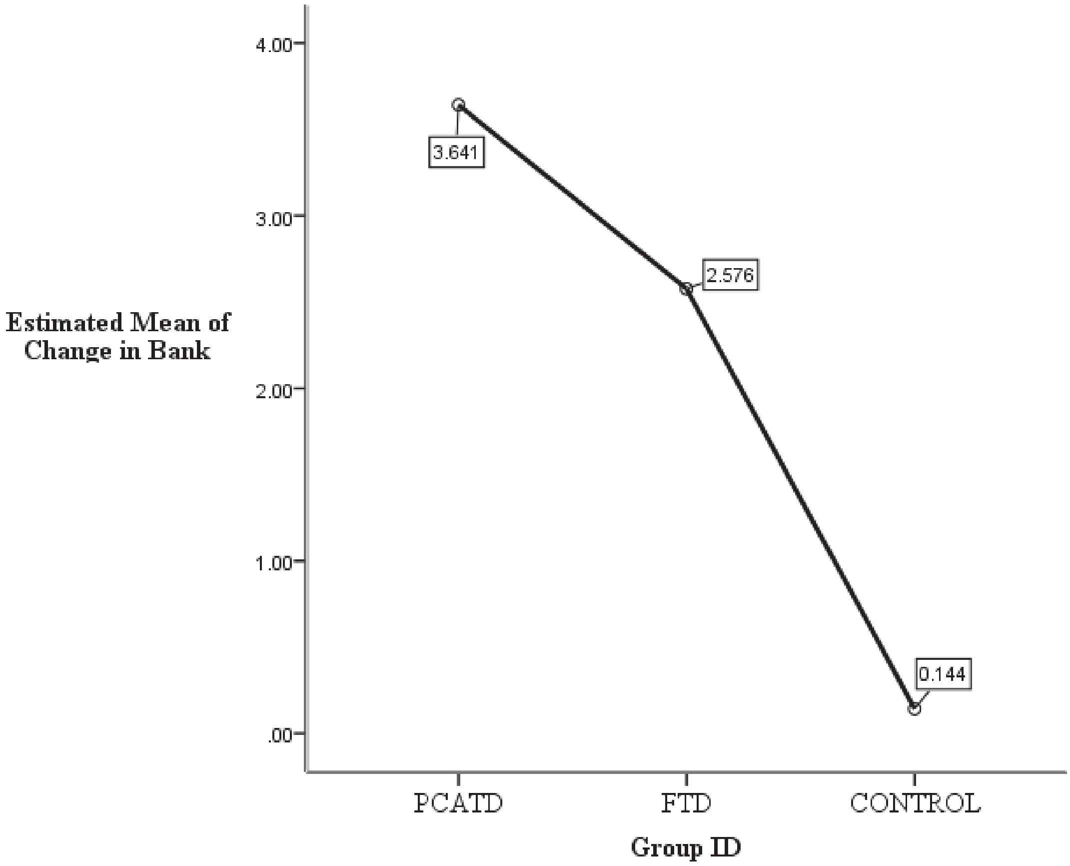


Figure 6-36. Post Hoc Bank Change Scores Means Plot

Altitude Variable

A 3x2 mixed model ANOVA was conducted to compare three groups of participants on Altitude performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90) = 26.107$, $p = .000$, $\eta 2 = .23$. There was no evidence of a difference between groups, $F(2, 90) = .517$, $p = .598$. In addition, there was no evidence of an interaction between group training and Altitude performance, $F(2, 90) = 1.11$, $p = .333$, $\eta 2 = .02$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-37, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

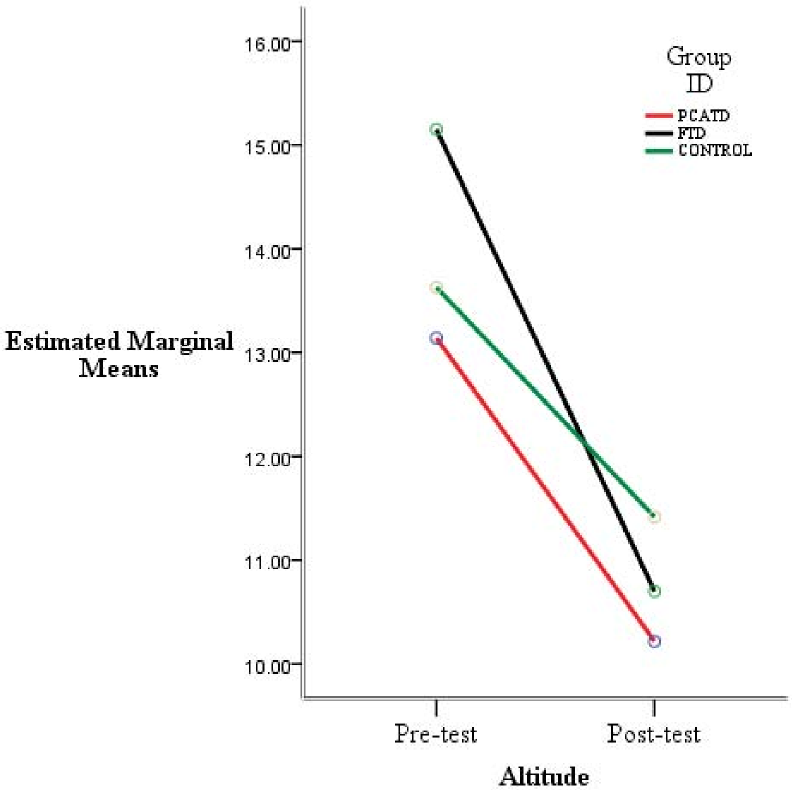


Figure 6-37. Means Plot Altitude Performance

Indicated Air Speed (IAS) Variable

A 3x2 mixed model ANOVA was conducted to compare three groups of participants on IAS performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90)= 8.41$, $p=.005$, $\eta 2 = .09$. There was no evidence of a difference between groups, $F(2, 90) =1.217$, $p =.301$. In addition, there was no evidence of an interaction between group training and IAS performance, $F(2, 90) =1.52$, $p =.224$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-38, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

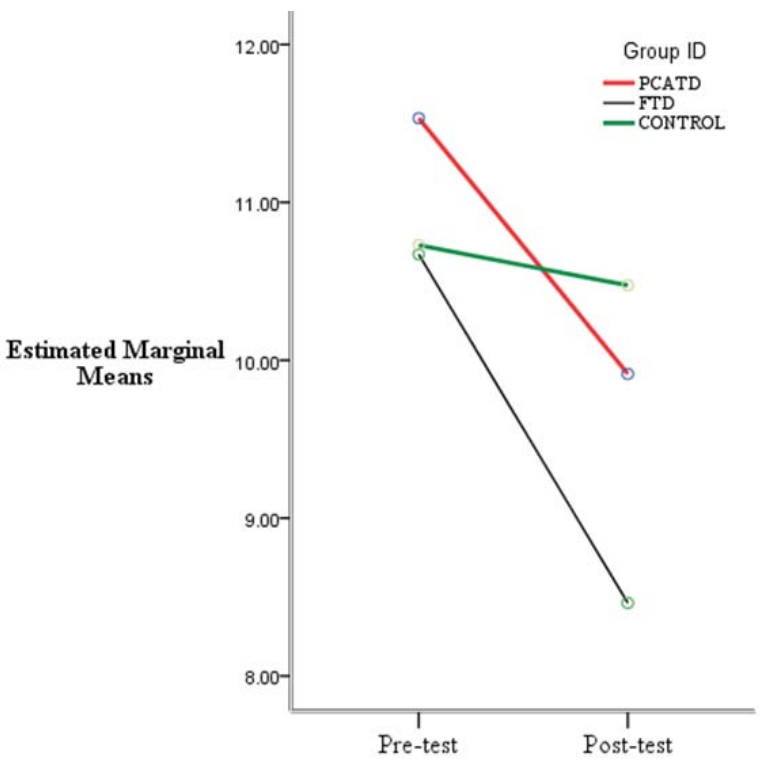


Figure 6-38. Means Plot Indicated Airspeed Performance

Heading Variable

A mixed model ANOVA was conducted to compare three groups of participants on Heading performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, F(2, 90)= 17.44, *p*=.000, η2 = .162. There was no evidence of a difference between groups, F(2, 90) =.510, *p* =.602. In addition, there was no evidence of an interaction between group training and IAS performance, F(2, 90) =1.30, *p* =.277, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-39, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

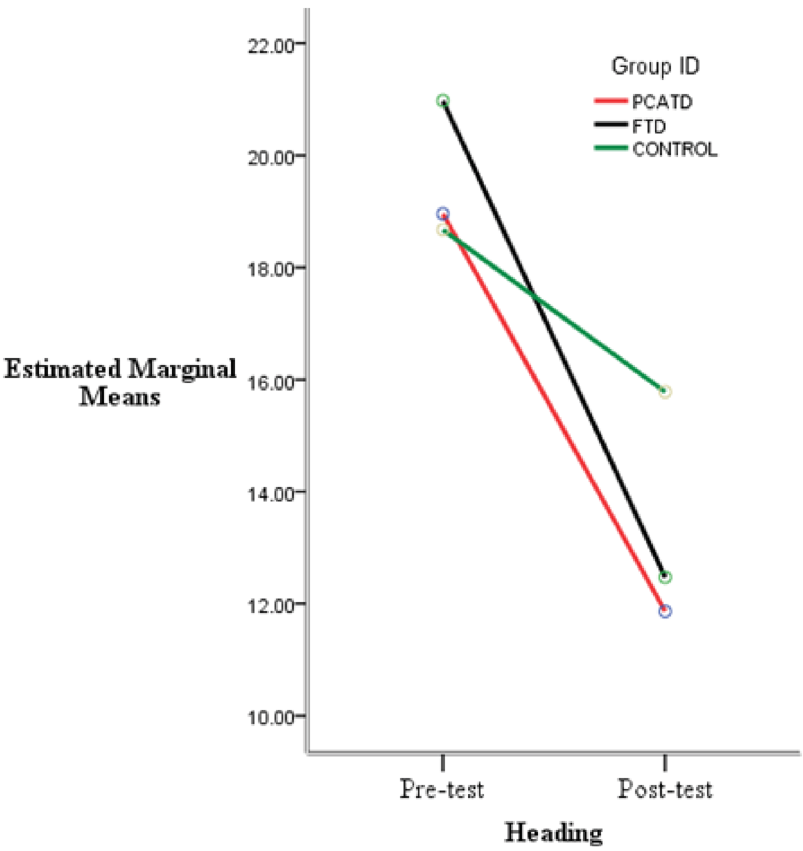


Figure 6-39. Means Plot Heading Performance

Total Variable Score

A mixed model ANOVA was conducted to compare three groups of participants on Total Variable Score (combined score of Pitch, Bank, Altitude, IAS, and Heading) performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90)= 35.69$, $p=.000$, $\eta 2 = .284$. There was no evidence of a difference between groups, $F(2, 90) =.211$, $p =.810$. However there was evidence of a significant interaction between group training and Total Variable Score performance, $F(2, 90) =3.36$, $p =.039$, $\eta 2 = .07$, which indicates that the groups did have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-40, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

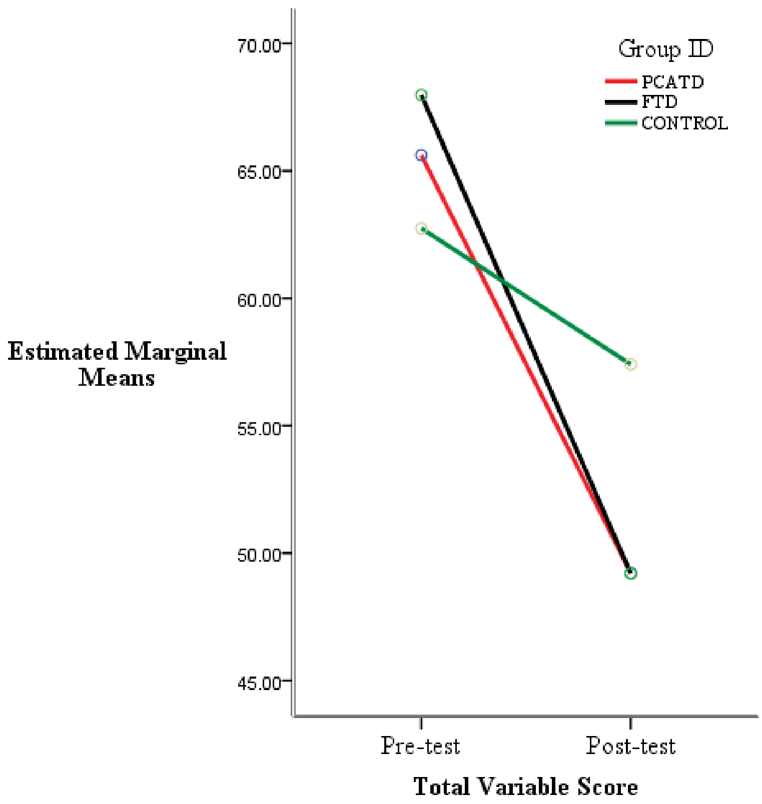


Figure 6-40. Means Plot Total Variable Score Performance

Post –Hoc Analysis of Interaction between Group and Total Variable Score Performance

Post hoc analyses using the Least Significant Difference post hoc criterion for significance indicated that there was significantly less improvement in Total Variable gain score performance in the control group (M=-5.33, SD=23.29) when compared to the FTD group (M=18.77, SD =19.71) and the PCATD group (M=16.40, SD =22.23) at the $p < .05$ significance level. However, there was no significant difference in Total Variable gain score performance between the PCATD group and the FTD group (see Fig. 6-41).

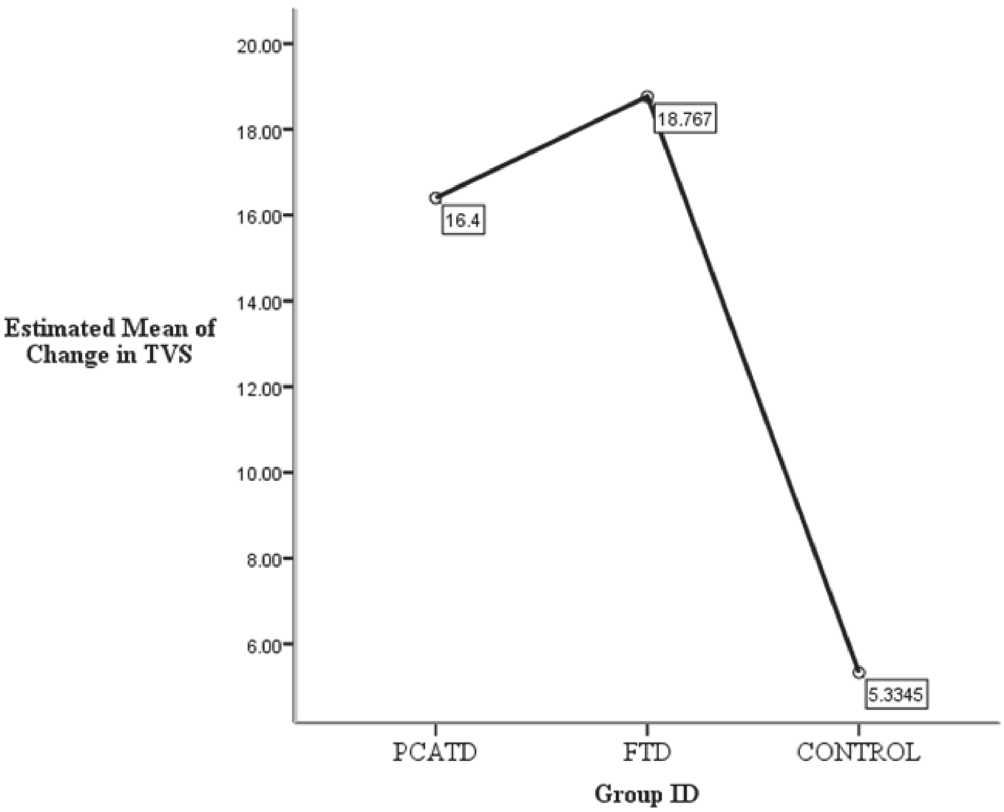


Figure 6-41. Post Hoc Total Variable Score Means Plot

Glide Slope Score

A 3x2 mixed model ANOVA was conducted to compare three groups of participants on Glide Slope Score performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found no evidence of a main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90) = .648$, $p = .423$, $\eta 2 = .007$. There was no evidence of a difference between groups, $F(2, 90) = .250$, $p = .780$. In addition, there was no evidence of an interaction between group training and Glide Slope score performance, $F(2, 90) = .297$, $p = .744$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-42, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

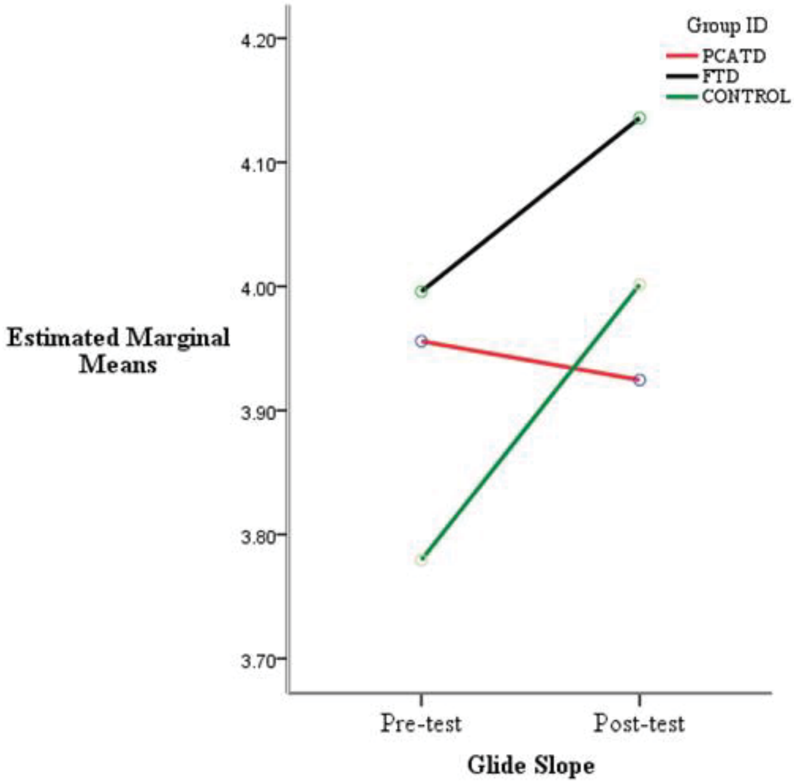


Figure 6-42. Means Plot Glide Slope Score Performance

Overhead Rejoin Pattern Score

A 3x2 mixed model ANOVA was conducted to compare three groups of participants on Overhead Rejoin Pattern score performance while completing a VFR Overhead Rejoin Manoeuvre. A 3x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(2, 90)= 14.63$, $p=.000$, $\eta 2 = .140$. There was no evidence of a difference between groups, $F(2, 90) =.378$, $p =.686$. In addition there was no evidence of a significant interaction between group training and Glide Slope score performance, $F(2, 90) =.585$, $p =.559$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-43, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

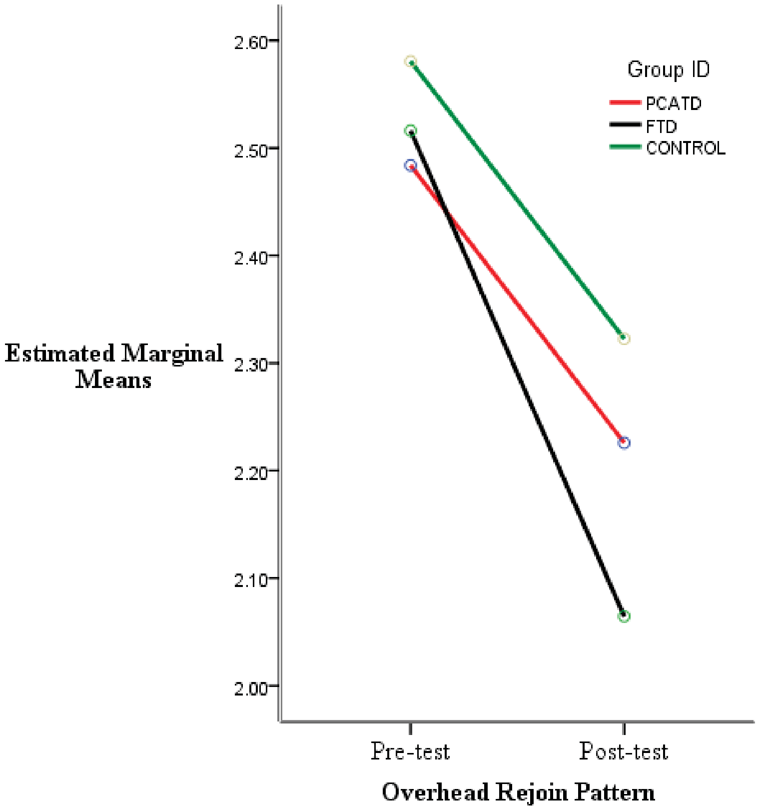


Figure 6-43. Means Plot Overhead Rejoin Pattern Score Performance

6.5.8.4 Participants Feedback on Research Question 1

At the conclusion of the first part of the experiment, the participants were asked whether their VFR task performance had improved when measured across the eight flight variables. The results are outlined in Table 6-26.

Table 6-26. Participants VFR Task Performance Feedback (Positive Responses)

VFR Task Performance Measure	FTD Trained *n*=31	PCATD Trained n=31
Maintaining correct altitude	20	20
Maintaining correct magnetic heading	28	25
Maintaining correct attitude (Pitch)	22	20
Implementing procedural turns (Angle of Bank)	25	24
Maintaining correct airspeed	30	29
Overall performance (Total Variable Score)	28	26
Intercept and maintain Glide Slope	14	12
Implementing a correct Overhead Rejoin pattern	18	17
Mean Value / Standard Deviation	23.13 / 5.59	21.6 / 5.47

The feedback indicated that the majority of participants believed that their VFR task performance skills improved after training on the FTD or PCATD. On average 23 participants (74%) who trained on the FTD and 22 participants (71%) who trained on the PCATD believed there was overall improvement in VFR skills. The highest number of participants who answered positively was in the VFR task - Maintaining Correct Airspeed, FTD (97%) and PCATD (94%). The lowest number of participants who answered positively was in the VFR task Intercept and Maintain Glide Slope, FTD (58%) and PCATD (55%). Capturing the glide slope on the PCATD was difficult, as the magnetic heading and speed have to be precise. The limited visual perspective of the PCATD is also quite different to the visual perspective generated by a FTD. Therefore, more work is required on improving depth of field and FOV in your area.

6.5.8.5 Research Question Two

Is there a significant difference in performance of a standard VFR traffic pattern operation on a low cost PCATD between pilots from two different flying training organisations and with different levels of aviation experience?

The purpose of this study was to ascertain if the training effectiveness of the PCATD could be affected by relocating it to another geographic location and by differing levels of aviation experience. Testing and training was completely solely on the PCATD. One group of participants was recruited primarily from Ardmore Flight School with the addition of pilot trainees from the Auckland region.

A second group was recruited primarily from Massey School of Aviation with the addition of pilot trainees from the Manawatu region. In addition, the participants were purposively sampled to ensure that that the two groups had different levels of aviation experience except for the fact that the all participants selected had very low PCATD experience. The rationale for this was to establish if prior aviation experience had any significant effect on rate of learning on the PCATD between the two groups.

6.5.8.6 Aviation Experience Levels (PCATD Study)

Data about the five aviation experience factors were obtained from a pre-test survey that was administered at the beginning of the study: Total Flight Time, VFR Flight Time, FTD Time, PCATD Time, and Recent Flight Time (see Appendix N).

The descriptive statistics of the Aviation experience levels (see Table 6-27) indicate large differences in variance in the independent variables between the two groups. The Auckland regional group (1) has considerably more flight training experience than the Manawatu regional group (2) in all categories except for PCATD training time. Also in Group 1 (Auckland region), 14 participants had a PPL and in Group 2 (Manawatu region), only one participant had a PPL.

Table 6-27. Comparative Statistics of Aviation Experience Levels (Hrs)

Aviation Experience (Hrs)_	Group ID	No.	Mean	SD
PCATD Time	1	28	0.40	.94
	2	28	0.21	.95
	Total	56	.31	.94
FTD Time	1	28	10.09	19.22
	2	28	0.14	0.43
	Total	56	5.11	14.37
Total Flight Time	1	28	498.90	975.30
	2	28	29.18	46.11
	Total	56	264.04	723.98
VFR Flight Time	1	28	387.96	839.60
	2	28	29.04	45.96
	Total	56	208.5	616.34
Recent Flight Time	1	28	15.42	20.54
	2	28	3.61	5.56
	Total	56	9.51	16.05

A Mean Plot of Aviation Experience visually demonstrates the large difference in variances of the independent variables between the two groups (see Fig. 6-44). Because of the large difference in variance between the two groups it is essential to test for homogeneity of variance. An underlying assumption of ANOVA is that the variance within each of the populations being analysed is equal. Two alternative versions of the F ratio, Welch (1951) and Brown Forsythe (1974), and a Means Plot can be used if the homogeneity of variance is broken (Field, 2012). Welch's F adjusts the residual degrees of freedom to resolve problems arising from violations of the homogeneity of variance assumptions. The Welch F adjustment controls Type 1 errors very well (Tomarken & Serlin, 1986).

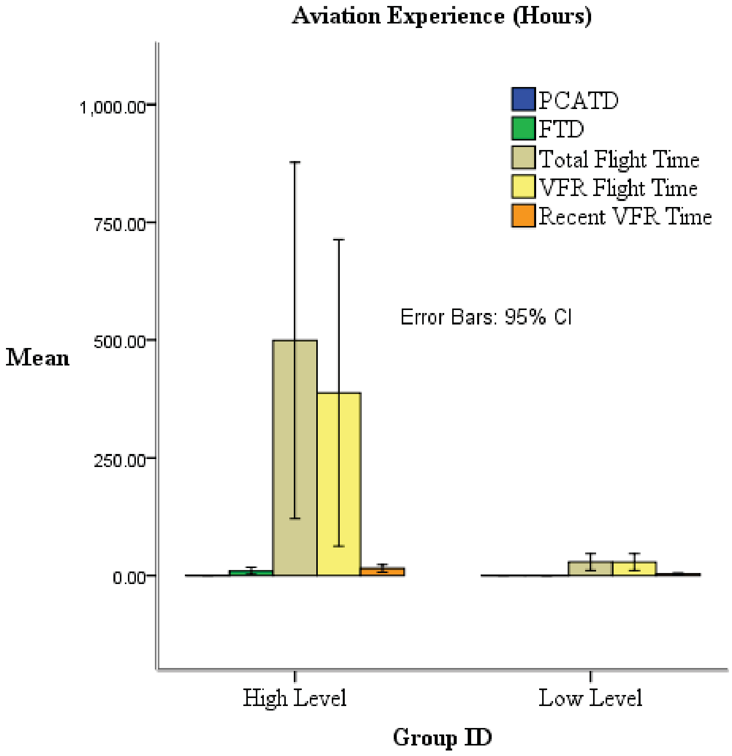


Figure 6-44. Aviation Experience Mean Plots

The Levene's test of Homogeneity of Variance indicates that apart from PCATD Training Time the other aviation experience variables were not homogenous. A one-way between subjects ANOVA was conducted to establish if there was a significant difference in the aviation experience of the participants assigned to the two groups. Due to the assumption of homogeneity being violated the Welch F ratio is reported (see Table 6-28).

Table 6-28. ANOVA Results-Aviation Experience

Aviation Experience (Hrs)	*df*	*df2*	*F(Welch)*	*Sig.*
PCATD Time	1	54	.519	.474
FTD Time	1	27	7.49	.011
Total Flight Time	1	27	6.48	.010
VFR Flight Time	1	27	5.10	.032
Recent Flight Time	1	31	8.52	.006

6.5.8.7 PCATD Initial Training Session Score & Final Training Score

A mixed model ANOVA was used to test the two groups of participants and their performance of a VFR Overhead Rejoin manoeuvre on the PCATD. One group had significantly more aviation experience (measured in hours) than the other group. The aviation experience was measured by Total Flight Time, VFR Flight Time, VFR Flight Recency, and training time spent on flight simulation devices (see Table 6-27). A familiarisation session was undertaken by participants where they learned the correct operation of the PCATD. This session was followed by three comprehensive training sessions on the PCATD, which were recorded and analysed. The performance measurement was based on NIFA scores (Error Rate) of six different VFR variables and a calculated deviation value for the seventh variable (Glide Slope). A comparison was made between the initial training session performance and the final session performance to ascertain if there was any significant difference in performance scores on the PCATD between the two groups.

The descriptive statistics for the two groups are listed in Table 6-29.

Table 6-29. Comparative Statistics of PCATD Training Scores of Two Groups

Group ID	**1 PCATD) (*n* =28)**		**2 PCATD) (*n*=28)**	
	Mean	SD	Mean	SD
Initial Pitch	6.08	2.34	6.29	3.59
Initial Bank	10.50	4.03	9.92	5.73
Initial Altitude	9.70	5.34	10.33	6.25
Initial IAS	14.51	13.08	13.48	9.16
Initial Heading	30.07	5.71	26.26	9.89
Initial Total Score	70.86	20.36	66.29	23.39
Initial Glide Slope	0.86	0.65	1.11	0.96
Final Pitch	5.00	1.57	5.65	2.38
Final Bank	7.93	3.49	9.39	5.15
Final Altitude	8.06	1.83	11.28	9.44
Final IAS	14.51	13.08	13.48	9.16
Final Heading	25.06	3.91	22.15	6.93
Final Total Score	56.18	8.04	58.5	21.44
Final Glide Slope	0.846	0.85.	1.09	0.933

Pitch Variable

A mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Pitch performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(1, 54)= 10.18$, $p=.002$, $\eta 2 = .16$. There was no evidence of a difference between groups, $F(1, 54) =.462$, $p =.500$. In addition, there was no evidence of an interaction between aviation experience and pitch performance, $F(1,54) =.659$, $p =.421$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-45, shows how each group performed in the Pre-test and Post- test, and with each line representing a group.

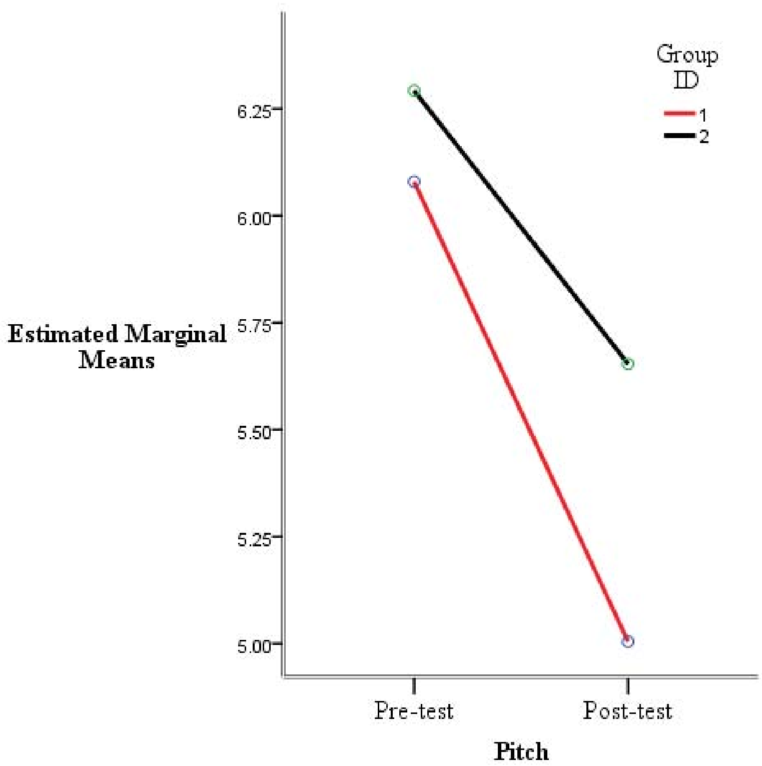


Figure 6-45 Means Plot Pitch Performance

Bank Variable

A 2x2 mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Bank performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 ANOVA found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores, $F(1, 54) = 9.45$, $p = .003$, $\eta 2 = .15$. There was no evidence of a difference between groups, $F(1, 54) = .147$, $p = .703$. In addition, there was significant evidence of an interaction between aviation experience and Bank performance , $F(1, 54) = 4.04$, $p = .049$, partial $\eta 2 = .07$. The significance level (with rounding) is exactly on $p=.05$ and so this is considered significant. This result may be due to the significant difference in FTD experience and total flight time between groups. Banking the aircraft in a balanced turn is a difficult VFR manoeuvre and it may take more experience and time to master the technique in the PCATD. A Means Plot described in Fig. 6-46, displays how each group performed in the Pre-test and Post- test, and each line represents a group.

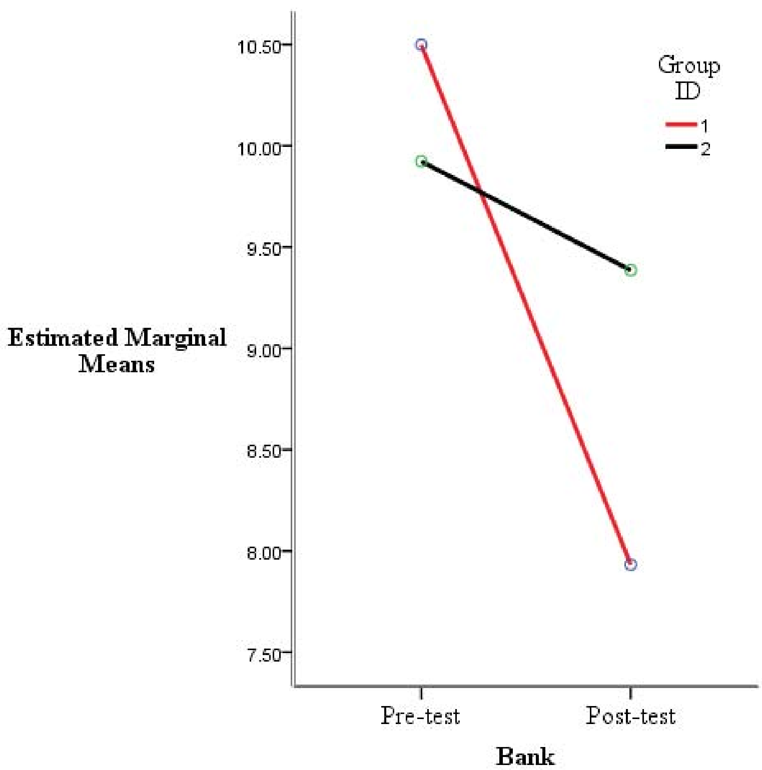


Figure 6-46. Means Plot Bank Performance

Altitude Variable

A 2x2 mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Altitude performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found no evidence of a main effect for the within subjects factors - Pre-test vs. Post-test scores of altitude, $F(1, 54) = .134$, $p = .716$. There was no evidence of a difference between groups, $F(1, 54) = 1.84$, $p = .181$. In addition, there was no evidence of an interaction between aviation experience and altitude performance, $F(1,54) = 2.00$, $p = .163$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-47 displays how each group performed in the Pre-test and Post- test, and each line represents a group.

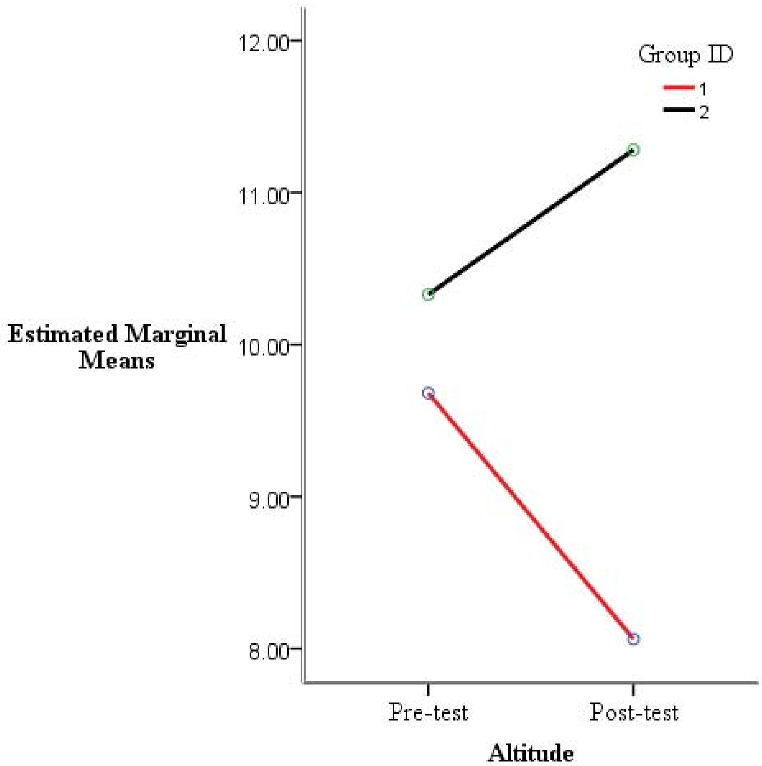


Figure 6-47. Means Plot Altitude Performance

Indicated Air Speed (IAS) Variable

A 2x2 mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on IAS performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found no evidence of a main effect for the within subjects factors - Pre-test and Post-test scores of IAS, $F(1, 54)= 6.85$, $p=.113$. There was no evidence of a difference between groups, $F(1, 54) =.078$, $p =.781$. In addition, there was no evidence of an interaction between aviation experience and IAS performance, $F(1,54) =.142$, $p =.707$, which indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-48, displays how each group performed in the Pre-test and Post- test, and each line represents a group.

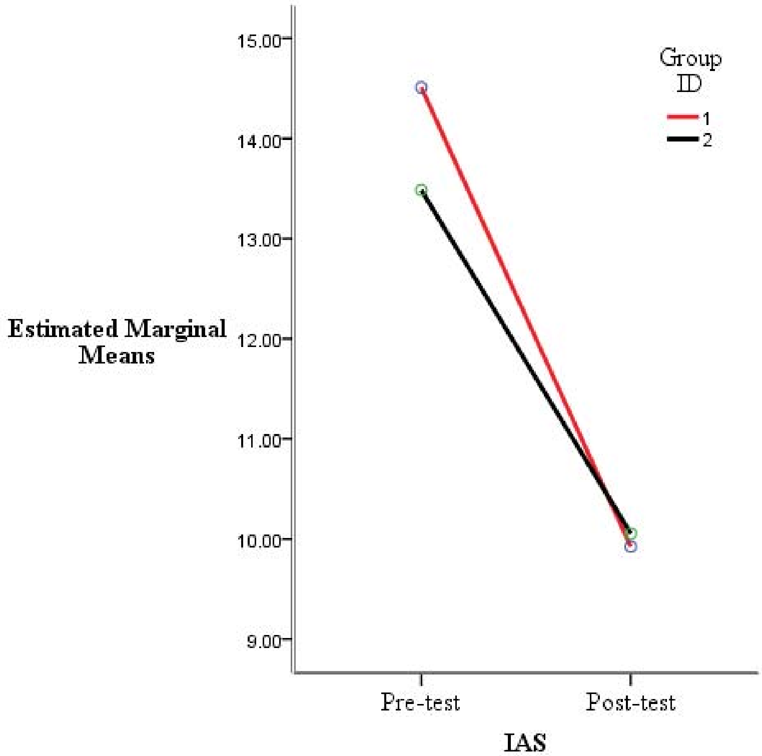


Figure 6-48. Means Plot IAS Performance

Heading Variable

A 2x2 mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Heading performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test vs. Post-test scores of Heading, $F(1, 54)= 30.30$, p=.000, $\eta 2 = .36$. There was no evidence of a difference between groups, $F(1, 54) =.3.42$, p =.070. In addition, there was no evidence of an interaction between aviation experience and Heading performance, $F(1, 54) =.288$, p =.594. This indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-49, displays how each group performed in the Pre-test and Post- test, and each line represents a group.

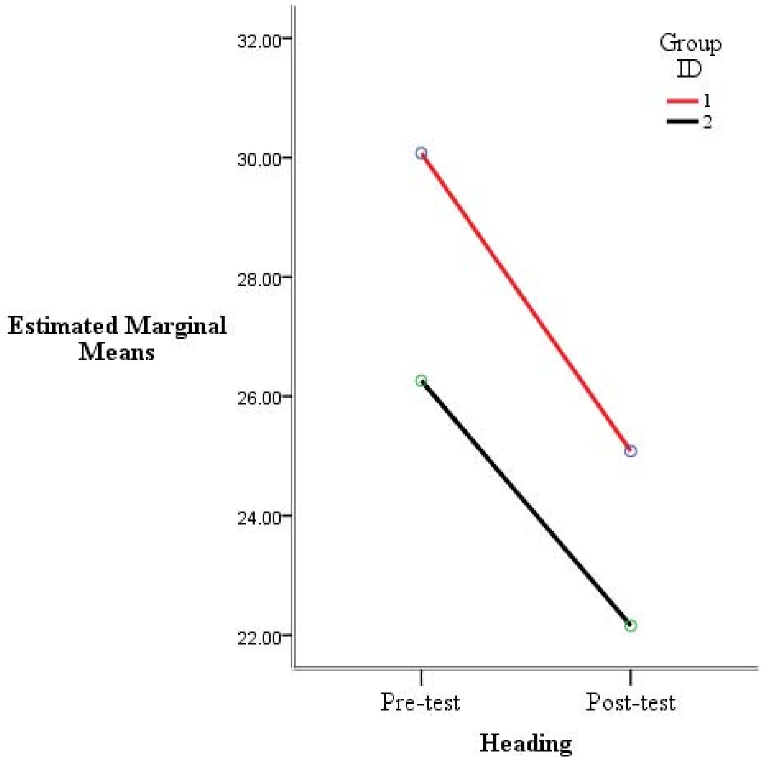


Figure 6-49. Means Plot Heading Performance

Total Score Variable

A mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Total Score performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found a highly significant main effect for the within subjects factors - Pre-test and Post-test scores of Total Score, $F(1, 54)= 27.40$, p=.000, $\eta 2 = .34$. There was no evidence of a difference between groups, $F(1,54) =.056$, p =.814. In addition, there was no evidence of an interaction between aviation experience and Total Score performance, $F(1, 54) =2.601$, p =.113. This indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-50, displays how each group performed in the Pre-test and Post- test, and each line represents a group.

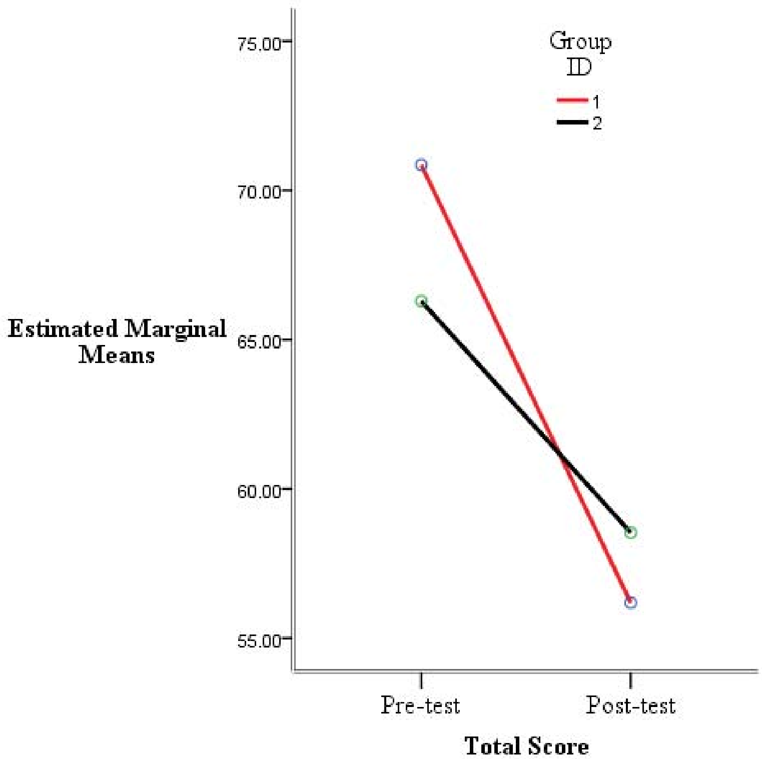


Figure 6-50. Means Plot Total Score Performance

Glide Slope Variable

A 2x2 mixed model ANOVA was conducted to compare two groups of participants (one group had significantly more aviation experience) on Glide Slope performance while completing a VFR Overhead Rejoin Manoeuvre. A 2x2 Analysis of Variance found no significant main effect when comparing individual Pre-test and Post test scores of Glide Slope, $F(1, 54) = .013$, $p = .911$. There was no evidence of a difference between groups, $F(1, 54) = 2.171$, $p = .146$. In addition, there was no evidence of an interaction between aviation experience and Total Score performance, $F(1, 54) = .001$, $p = .975$. This indicates that the groups did not have significantly different changes from Pre-test to Post-test scores. A Means Plot described in Fig. 6-51, displays how each group performed in the Pre-test and Post- test, and each line represents a group.

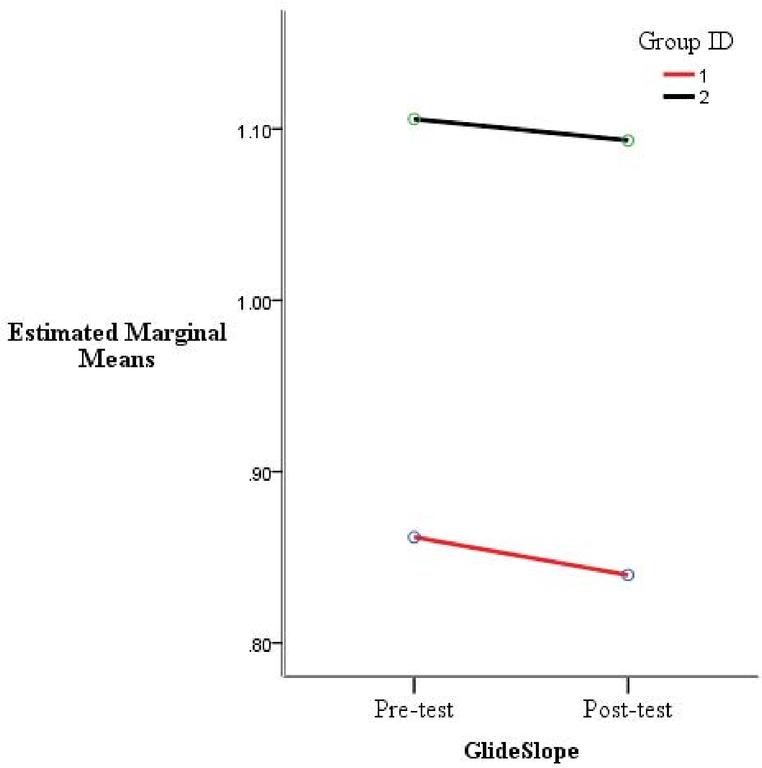


Figure 6-51. Means Plot Glide Slope Performance

6.5.8.8 Participants Feed Back on Research Question 2

At the conclusion of the second part of the experiment, the participants were asked if they thought their VFR task performance had improved when measured across the seven flight variables. The results are outlined in Table 6-30.

Table 6-30. Participants PCATD VFR Task Performance Feedback

VFR Task Performance Measure	Auckland Region – N=28	Manawatu Region N=28
Maintaining correct altitude	18	16
Maintaining correct magnetic heading	**27**	25
Maintaining correct attitude (Pitch)	22	20
Implementing procedural turns (AOB)*	22	23
Maintaining correct airspeed	24	26
Overall Performance (Total Variable Score)	25	21
Intercept and maintain Glide Slope	12	10
Mean Value / Standard Deviation	21.33 / 5.02	20.6/ 5.58

*Angle of Bank

The feedback indicated that the majority of participants believed that their VFR task performance skills improved after training on the PCATD. On average 21 participants from the Auckland region (75%), and 21 participants (75%) from the Manawatu region thought there was overall improvement in their VFR skills while completing the Overhead Rejoin Procedure. The highest number of participants from the Auckland region who answered positively was in the VFR task - Maintaining Correct Magnetic Heading, PCATD (96%). The lowest number of participants from the Auckland region who answered positively was in the VFR task - Intercept and Maintain Glide Slope, PCATD (43%). The highest number of participants from the Manawatu Region who answered positively was in the VFR task - Maintaining Correct Airspeed, PCATD (96%). The lowest number of participants from the Manawatu region who answered positively was in the VFR task - Intercept and Maintain Glide Slope, PCATD (36%).

6.5.9 Discussion

A review of the findings related to the two research questions is presented. Some of the discussion relates to the literature review in Section 4.6.3.

6.5.9.1 Discussion-Research Question 1

Is the Stage 4 SAV2 PCATD as effective as a NZ CAA certified FTD at improving pilot proficiency in the performance of a standard VFR traffic pattern operation?

The data was normally distributed, samples were independent and equal in number, and variances of populations were equal. The statistical tests that were chosen to analyse the data were mixed model ANOVA and Post-hoc Least Significant Difference (where applicable). The method was robust in that there were two experimental groups and one control group in the research design. Any adverse effects caused by extraneous variables was minimised by changing the geographical location and flight training environment, the use of two FTDs (identical in operation) and one PCATD, and a selection of participants from twelve different aviation training and educational organisations.

Mixed model ANOVA tests on aviation experience, pre-test scores, and post-test scores indicated that there was no significant difference between the three groups. In terms of pre–test scores, this meant that any effects on performance that may be caused by previous history such as prior aviation experience were minimised. Post-test effects such as practice effect[27] and maturation[28] had to be addressed. No significant difference was noted in post-test scores between the three groups, which indicated that practice effect was minimal or affected each group equally. In addition, the effect of maturation was minimised by ensuring that there was only a relatively short time (several hours) between pre-testing and post testing of participants.

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[27] Testing practice effect is where subjects tend to increase their scores on second and subsequent administrations of a test because of familiarity with the format of the test (McDaniel & Fisher, 1991).

[28] Maturation is a process where subjects change during the course of the experiment or even between measurements. This could include long term effects such as ageing or short term effects such as fatigue (Brewer, 2000)

The key measure of VFR task performance was the change in Pre-test vs. Post test score that provides a measure of each participants VFR task performance improvement. The NIFA score for each variable provides an error rate per second value for the pre-test and post-test score. For improvement to be achieved the post-test error rate should be less than pre-test error rate. The magnitude of the difference provides some indication of the magnitude of the improvement in VFR task performance. Mixed model ANOVA indicated a significant interaction between groups in three VFR performance variables: Pitch, Angle of Bank, and Total Variable score.

There was no evidence of a significant difference in Pre-test vs. Post-test change scores across all of the eight variables between the FTD group and the PCATD group. This indicated that VFR task training (e.g., Overhead Rejoin Procedure) was just as effective when completed on the low cost PCATD as it was on the certified FTD. To support this finding, the results indicated that the control group did not perform the VFR overhead rejoin task as well as the other two groups. Three of the eight VFR task performance variables reached significance ($p < 0.05$) and the post hoc LSD test indicated that the control group's Pitch variable change score and the Total variable change-score (i.e., combination of Pitch, Heading, Altitude, Angle of Bank, and Indicated Air Speed variables) was significantly less than the change scores of the FTD group and the PCATD group. The post hoc LSD test also indicated that the control group's angle of bank change score was significantly lower than the angle of bank change scores of the FTD group and the PCATD group.

No significant differences in performance were found between the three groups in relation to Heading, Altitude, IAS, Glide slope, and Overhead Rejoin Pattern. However, evidence of the effectiveness of PCATD training compared to no training, was supported by the significant differences found between the PCATD group and the Control group in the Total Variable Score, which represented the combined scores of five of the eight flight performance variables. Taking into account the random assignment of participants to one of the three groups and the homogeneity of their aviation experience levels, pre-test and post-test scores, the results indicated that lack of training on either the PCATD and FTD significantly impaired the control group's VFR task performance.

Also training on the CAANZ certified FTD provided no advantage over the PCATD in relation to rehearsing advanced VFR exercises such as the Overhead Rejoin procedure. McDermott (2005a) completed a similar quasi transfer study that compared the instrument landing approach performance of 63 pilots randomly assigned to either a PCATD or FTD for training. The FTD trained group was designated as the control group and the PCATD group the treatment group. A pre-test and post-test was conducted on the FTD before and after the training. The results of McDermott's study found no significant difference in instrument landing approach performance between the group trained on the PCATD and the control group.

The current study differed somewhat from McDermott's (2005a) research design. Although group size was similar (approx. 30 participants) a control group (that received no training) was also included in the current study. McDermott's study used flight instructor evaluations of ten variables and a total score variable. However, a high number of these scores showed no change (zero score) in pilot proficiency between the pre-test and post-test assessments, which resulted in a non-normal data distribution.

The current study used objective measurement by analysing flight-recording data of FTD and PCATD flight variables. This method provided an unbiased precise measurement of VFR task performance and also produced normally distributed data. Only one measurement, the Overhead Rejoin Pattern was too complex for mathematical analysis and required a categorical assessment by flight instructors.

Very few studies were found that used objective measurement in an aircraft or flight simulator instead of subjective evaluation by SMEs. Roessingh (2005) used objective measurement in the form of special recording equipment installed on the aircraft that recorded twelve flight variables including altitude, IAS, and rates of turn. Only one study was found in the literature review that combined objective measurement with flight task performance in a PCATD. Smith and Caldwell (2004) used a fixed base F-117 simulator to record flight performance parameters of F-117A pilots undergoing training. Combining flight simulation and objective measurement has only occurred in the last decade e as this type of recording technology has only become available on the relatively new models of commercially produced FTDs and PCATDs.

New general aviation aircraft with glass cockpits also have flight data recording capability and flight data for a particular sortie can be easily downloaded from the glass cockpit (i.e., Primary Flight Display or Multi-Function Display). It is hoped that flight data recording, flight data retrieval, and flight data analysis, will become more popular data retrieval tools for research purposes. An objective method that uses simulator-recording technology is cost effective, accurate and can be operated in a strictly controlled environment.

One advantage of the PCATD was that some task procedures were easier to accomplish than in the real aircraft. For example, most participants believed that maintaining airspeed in the FTD and PCATD was easier to do than in the real aircraft. This was due to a number of environmental factors that are strictly controlled in PCATDs, such as lack of low-level turbulence, perfectly performing engines, and stabilised flight instruments. In the aircraft, low-level turbulence, slight surges in engine power, vibration and shake in flight instruments are always omnipresent and can affect pilot performance. Also, the flight models used in the FTD and PCATD provided a fast response to throttle control and flight control inputs. This enabled the participants to adjust power settings frequently and get rapid feedback as to the effect on flight performance. The participants agreed that this responsive feedback provided effective training and they thought that the acquired skills would easily transfer effectively to the aircraft. The Intercept and Maintain Glide Slope skill was more problematic. In both the FTD and the PCATD the simulated airport did not have an Instrument Landing System and because it was a VFR exercise the glide slope had to be estimated visually and with reference only to basic flight instruments. Both the PCATD and FTD visual display systems have limitations in terms of depth of field (DOF) and field of view (FOV) compared to aircraft in flight. Both groups of participants struggled to improve this VFR skill and fly consistent approaches in the PCATD and FTD. They indicated that this skill would be the least likely to transfer effectively to the aircraft.

This study involved the development and evaluation of a low cost PCATD that could be as effective as a CAANZ certified FTD at training transfer of a VFR task procedure (Overhead Rejoin Manoeuvre). The results have added to the limited body of research examining the effectiveness of PCATDs for VFR training. There was no significant difference in performance of a VFR Overhead Rejoin Manoeuvre between those participants who trained on a PCATD compared to those trained on the FTD.

Also the use of objective measurement tools has provided a significant contribution to the limited research on how PCATDs can be utilised for the objective evaluation of pilot performance.

6.5.9.2 Discussion-Research Question 2

Is there a significant difference in performance of a standard VFR traffic pattern operation on a low cost PCATD between pilots from two different flying training organisations and with different levels of aviation experience?

The second part of the study was to ascertain if the training effectiveness of the PCATD could be affected by changing certain factors such as aviation experience, geographic location, flight-training environment, and unfamiliarity with the training device.

This study was based on a non-equivalent group, pretest-posttest design that partially eliminates a major limitation of the non-equivalent group, post-test only design. At the start of the study, an empirical assessment was undertaken to record the differences in aviation experience within the two groups.

If one group performs better than the other on the post-test, initial differences (if the groups were not significantly different in the pre-test) can be ruled out as explanations for the post test differences. However if groups differ at the onset of the study in their pre-test scores, any differences that occur in test scores at the conclusion are difficult to interpret (Gibbons & Herma, 1997).

In terms of aviation experience, there were significant differences between the two groups of participants. A deliberate decision was made to form the groups in a purposive way to establish if significant prior aviation experience would have any effect on VFR task performance solely on the PCATD. The results indicated there was no significant difference in the initial training score across the seven variables between the two groups that trained on the PCATD. The results also indicated there was no significant difference in the final training score across all of the seven variables between the two groups that trained on the PCATD. This indicated that practice effect or maturation, had minimal influence on the final training score.

Finally the null hypothesis was supported in that there was no significant difference in the change scores (Initial training error score-Final training error score) across six of the variables and marginal significance for the Bank variable ($p=.049$) between the two groups that trained on the PCATD.

Participants of the two PCATD groups reported that practicing the VFR procedures, maintaining airspeed and magnetic heading in the PCATD was easier than in the real aircraft. This was mainly due to the high level of flight stability in the PCATD. The flight model in the PCATD was accurate and provided a fast response to all flight control and throttle inputs. In a similar way to the first study, participants were able to adjust flight control settings frequently and receive prompt feedback on flight performance. The participants agreed that the overall fidelity of the PCATD was sufficient to provide effective training and they thought that the acquired skills would transfer effectively to the aircraft. However, flight control (e.g., Yoke, Throttle, & Rudders) sensitivity was a fidelity issue that influenced participants' perception of skill improvement in three VFR performance variables; altitude, attitude, and angle of bank. These variables affect flight control and this was more difficult in the PCATD compared to the FTD or aircraft. Because of this limitation, there was less skill improvement in these variables, compared to airspeed and magnetic heading. Airspeed is mainly controlled by throttle control and magnetic heading by use of rudder controls with small inputs from the flight controls. However the participants reported that the use of additional controls (e.g., Elevator Trim Control & Flaps Control) did assist with all flight conditions and meant that the overall parameters were able to be achieved.

As described in the first part of the study, the participants found the Intercept and Maintain Glide Slope skill difficult to improve. The simulated airport in the PCATD did not have an Instrument Landing System and because it was a VFR exercise the glide slope had to be estimated visually and with reference only to basic flight instruments. In particular, the PCATD's visual display system also had a low depth of field (DOF) compared to aircraft in flight. This meant both groups of participants had to work hard to improve their VFR task skills and fly consistent glide slope approaches in the PCATD. They indicated that this skill would be the least likely to transfer effectively to the aircraft.

The feedback from participates in both parts of the current study was similar to the feedback obtained by Beckman (2009), in that the Stage 4 PCATD was best suited for navigation training and VFR procedures training but could also be effective for basic instrument training . Beckman examined the effectiveness of MSFS software for IFR training. Thirteen hundred survey respondents indicated that the skills of instrument approach procedures, holding patterns, basic instrument flight, and navigation were frequently practiced on MSFS and are found to be effective for both initial training and for maintaining proficiency. In addition, over 85% of responding pilots indicated that they used MSFS to preview approaches at unfamiliar airports, and 88% of these pilots found the software package effective for this task.

A number of studies have supported the effectiveness of PCATDs in IFR skills training but expressed reservations about their effectiveness for VFR skills training (Dennis & Harris, 1998; Johnson & Stewart II, 2005; Roessingh, 2005; Taylor, et al., 1999). For the first time the two comparative studies reported here have demonstrated that with the addition of large multiscreen monitors, detailed high resolution scenery and improved flight control and instrument panel fidelity, low cost PCATDs can be as effective as FTDs in training ab-initio pilots in VFR based manoeuvres and psychomotor skill training applications. These studies were representative of only a few that used objective measurement tools in evaluating pilots VFR performance in a PCATD. It is hoped the techniques developed in these studies will encourage more investigation into objective measurement of pilot performance using FTDs and PCATDs

6.6 Stage 5: Development of Massey School of Aviation Diamond DA 40 PCATD

6.6.1 Introduction

The Massey University School of Aviation upgraded its fleet of training aircraft in 2009. This new $8 million acquisition consisted of twelve Diamond DA 40’s single-engine aircraft, and two high performance Diamond DA 42 twin-engine aircraft. A distinctive feature of the Diamond DA 40 and the Diamond DA 42 is that they are equipped with a state of the art Garmin 1000 glass cockpit suite. Because these general aviation aircraft operate automated navigation, and flight management systems, the existing training syllabus had to be modified so that required competencies could be reached at an early stage (Massey News, 2009). At the time of this significant capital purchase and acquisition, there were insufficient funds to purchase a commercial FTD to support the new aircraft fleet.

Once again, the challenge was to develop a relatively low cost PCATD that could replicate the single engine Diamond DA 40. However, this PCATD project design represented a significant increase in training and simulation capability compared to previous projects. For example, it involved the development of a glass cockpit, and a large multi view display. Another technological innovation was the addition of a two degrees of freedom (2DOF) electrically actuated motion platform. The PCATD was developed to fulfil the following operational and research requirements:

1. Aviation research (Glass cockpit, Motion Technology, Threat & Error Management);
2. Instrument Flight Rules Rating & Recency training;
3. Ab-initio VFR Flight training;
4. VFR Remedial Navigation training;
5. VFR Scenario based training;
6. Human Factors training;
7. Achieve NZ Civil Aviation Certification as an approved VFR & IFR PCATD.

6.6.2 Literature Review

Since 1953, general aviation cockpit displays have been based on analogue (round dial) technology. These gauges were driven by airflow, mechanical gears, and electrical signals. In the last ten years, cockpits of light aircraft have undergone a rapid transition from conventional flight instruments to integrated, computerised displays known as glass cockpits.

6.6.2.1 Introduction

The General Aviation Manufacturers Association (GAMA) indicated that by 2006, more than 90 per cent of new piston-powered, light aircrafts were equipped with full glass cockpit displays (Goldston, 2010). Several manufacturers of glass cockpit displays now produce displays with supplemental type certification for retrofit installation to existing aircraft. This means that the number of aircraft equipped with full glass cockpits will continue to grow rapidly. However, the introduction of this advanced technology into light aircraft has brought a new set of safety concerns. It has also meant major changes to equipment design and operation, pilot performance and training, and accident investigation techniques.

There has also been an increase in the development of Desktop Trainers, PCATDs, and FTDs that replicate the complex functions of glass cockpit aircraft. The simulation of analogue cockpits in flight simulators has utilised mature electro-mechanical technologies to drive traditional instrument displays. This technology is well established but is becoming obsolete due to the rapid introduction of glass cockpit aircraft. Now powerful PCs combined with sophisticated software and high resolution graphic cards are being use to emulate all the complex functionality and operational modes of glass cockpit instrumentation such as the Garmin 1000 PFD and MFD displays (Garmin, 2008).

Legacy motion platforms for flight simulators are complex, expensive, and mostly driven by cumbersome hydraulic systems. The development of motion platforms driven by electric motor actuators and coupled with the increased power and versatility of PC-based technology has driven costs down dramatically. Motion platforms for use in FTDs now cost hundreds of thousands of dollars instead of millions of dollars. A very low cost motion platform ($20,000-$30,000) was sourced for this Diamond DA 40 PCATD project. This device provides motion simulation capabilities that until a few years ago were only available on the ICAO Level VI flight simulators.

6.6.2.2 PCATDs and Glass Cockpit Technology

Traditional flight instruments are being rapidly replaced in many general aviation aircraft with two LCD screens, the primary flight display (PFD), and the multifunction display

(MFD). Information previously displayed on separate instrument dials is now displayed on these screens including moving map displays, terrain, weather, aircraft traffic, engine data, and navigation information. Historically, in aircraft equipped with analogue instruments, pilots assessed aircraft position (both vertically and horizontally) relative to the ground. This assessment required the pilot to exercise cognitive mental processes of space, time, and altitude orientation. Now, with the new glass cockpit technology, pilots have a moving map and greater visual situational awareness. Therefore, the cognitive processing requirement is lower because of the comprehensive visual presentation of data (McDermott & Smith, 2006). However, one problem that has become apparent is that the reduction in cognitive processing due to lower levels of input from the pilot may lead to automation complacency. Recent research has found that some pilots may be spending too much time monitoring flight systems rather than actively flying (Bustamante & Clark, 2010). Nevertheless, other empirical studies have demonstrated performance advantages in using these type of interfaces in complex, real-world systems, including aviation (Vicente, 2002).

Proponents of ecological interface design (EID)[29] argue that glass cockpit type interfaces designed for complex systems should allow the pilot to perceive low-level physical system properties as well as abstract, higher level properties of the system. A key concept of EID is that the design allows direct perception of the state of the world with respect to the system goal as well as boundaries of successful performance (Vicente & Rasmussen, 1992). Lintern, Waite, and Talleur (1999) stated that increasingly complex cockpits could affect a pilot’s ability to acquire, comprehend, and act on the information. They argued that pilots who directly perceive and interact with critical flight properties might acquire and maintain basic piloting skills more efficiently than pilots who cannot observe such properties.

[29] Ecological interface design (EID) is an approach to interface design that was introduced specifically for complex sociotechnical, real-time, and dynamic systems. It has been applied in a variety of domains including aviation (Vicente & Rasmussen, 1992).

Due to the perceived advantages of this new technology an increased level of research has been directed at determining the effectiveness of glass cockpit displays for use in general aviation training. In addition, a number of studies have examined the effectiveness of glass cockpit displays compared to legacy analogue displays. This has been particularly useful for general aviation training, as a number of high profile accidents involving newly introduced Technically Advanced Aircraft (TAA) aircraft prompted safety concerns (Goldston, 2010). Coupled with the increased level of research there has been a number of safety related investigations by aviation authorities into the use of glass cockpits for general aviation training.

Smith, Fadden & Boehm-Davis (2005) completed a study where twenty pilots performed flight manoeuvres on a PCATD over three levels of workload with either a conventional or an alternative display that displays functional information. This functional information was similar but more simplified than a standard glass cockpit display. It contained horizontal and vertical bars, which changed in length depending on changes in altitude and speed of the simulated aircraft. The pilots ranged in age from 25-63 years, with a mean age of 42 years. The pilots' flight hours ranged from 1600-24,000 hours, with a mean of 5051 hours. All pilots had current IFR certification, with fifteen certified as flight instructors.

A Cessna 172 was simulated on the PCATD. The OZ[30] display was displayed over the Cessna instrument panel using MSFS 2002 (see Fig. 6-52). The secondary task used a GPS instrument simulated and displayed on the right side of the display screen. A second PC collected the data produced by MSFS 2002 and the OZ system. The pilots performed a number of VFR manoeuvres including straight and level, banking, stalling, climbing turns and slow straight and level flight. The manoeuvres were performed under three different workloads: low workload (no secondary task and no turbulence), medium workload (no secondary task with turbulence), and high workload (secondary task with turbulence).

[30] The OZ display integrates physical information represented via analogue dials on a standard instrument display into a series of basic perceptual forms, such as vertical and horizontal lines (Bennett & Flach, 1992)

The results of the pilots' performance with the functional display (OZ) showed greater control of thrust power and position (than with the conventional display), as well as improved performance on the secondary GPS related task. Smith et al's (2005) study was significant as it showed even rudimentary glass cockpit displays could have a beneficial training effect.

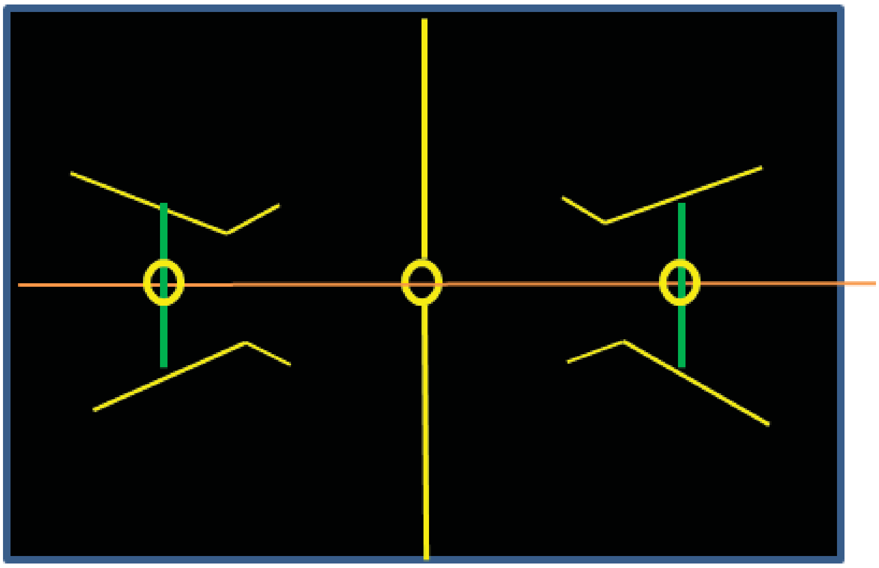

Figure 6-52. OZ Glass Cockpit Display (Facsimile)

Source: (Smith, et al., 2005)- Use of a Functional Aviation Display Under Varying Workload Conditions. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 49: 59-63.

Smith (2008) completed a qualitative analysis of three aircraft manufacturers (that provided glass cockpit training with aircraft purchases) and one university's aviation-training programme. Cirrus, Cessna, Avidyne, and Bowling Green State University were rated on three criteria to determine critical items for transition training to glass cockpits, as well as provide insight into aviation training industry strengths and weaknesses. The three criteria were course structure, training requirements, and evaluation.

1. In 2003, Avidyne produced the first general aviation integrated glass cockpit and provided basic interactive training software to emulate its Flight Max EX5000 PFD and MFD. This training simulation support was at the most elementary level, and represented the equivalent of a digital training manual for use by pilot trainees;

2. Bowling Green State University is a Collegiate Flight School under the Federal Aviation Regulations for both Part 61 and 141. This four-year university offers a digital cockpit transition-training course at the ab-initio level of flight training. The course structure was approximately four to six days. Training requirements were structured as a nine-hour ground-training course and a nine-hour flight-training course. The flight training was comprised of six lessons, the first being a two hour simulation unit in a PCATD to ensure the student was both instrument competent, and autopilot competent prior to flight training in the transition course;
3. Cessna Aircraft Company is an aircraft manufacturer with its own a pilot training department. The company provides a three-day course with eight hours of ground training and four to six hours of flight training and Cessna used desktop simulators to train pilots in the G1000 digital instrumentation system;
4. Cirrus is also an aircraft manufacturer with a pilot training programme. Course structure for the transition training was three days for a VFR certification or five days for an IFR certification. Training requirements developed by Cirrus detailed a transition syllabus with a minimum of 10 hours of flight training where three hours could be completed in an approved FTD.

A panel of experts were co-opted to evaluate the analogue to digital transition programmes of the various flight training organisations and some of their recommendations were as follows (Smith, 2008):

1. The training should be comprised of a blend of skills-set and scenario-based training;
2. Training should be in both visual and instrument flight rules, with an emphasis placed on achieving a high degree of instrument competency;
3. Flight training should be comprised of the following concepts: Basic VFR operations, instrument approaches, abnormal and emergency approaches;
4. There should be a total of nine hours of flight training (seven hours should be in the aircraft and a maximum of two hours in an approved FTD or PCATD).

The research findings emphasised the importance of using PC-based tutorial software. Desktop trainers, FTDs, and PCATDs in the transitional ground-based and flight- training programme. However, research was also required into establishing whether these new methods of training were as effective as traditional techniques. Craig, Bertrand, Gosset, &Thorsby (2005) compared the use of Technically Advanced Aircraft (TAA) with glass cockpits, an adapted syllabus, and scenario-based flight exercises with traditional methods for training student pilots. The data from this project indicated that trainee pilots using TAAs had to repeat more (61% vs. 17%) flight exercises than those in legacy training aircraft before the first solo, but had to repeat less flight exercises during private pilot and VFR cross country phases of training (15% vs. 38%) and during instrument training (24% vs. 45%).

A subsequent study compared VFR performance between traditional and new cockpit technologies. Johnson (2011) compared the VFR task performance of participants using a glass cockpit and analogue instrument panel in a Diamond DA 40 PCATD developed at the Massey University School of Aviation. Twelve student pilots (total flight training experience was on TAA aircraft) completed some VFR tasks such as steep rate turns, medium rate turns, and recovery from unusual attitudes using a glass cockpit configuration and then an analogue instrument configuration. The National Intercollegiate Flying Association (NIFA) scoring system was used to rate the VFR task performance of the participants (in a similar way to the methodology of the comparative study of this thesis). The participants were randomly assigned to two groups, and completed training, and then evaluation on the PCATD. One group completed the training on the analogue cockpit first followed by the glass cockpit configuration, and the training was reversed for the second group. The standby analogue gauges were disabled for this study and a six-pack of analogue gauges were digitally displayed in the PFD and MFD screens (see Fig. 6-53).

The study results demonstrated that the increase in error rate in altitude, bank angle, heading and airspeed was unacceptable in terms of safety, and indicated that students trained in TAA may face difficulties when reverting to analogue instrument panels in legacy aircraft. There was a 55% increase in flight variable error rate when completing turn maneuvers in the analogue cockpit compared to the glass cockpit. However, the difference in reaction time to recovery from unusual attitudes was not significant, when using the different cockpit configurations. Participants indicated that unfamiliarity with the analogue instruments, the different instrument scans required for each cockpit, and analogue instrument lag were possible factors that contributed to their increase in error rate when completing the VFR exercises using the more unfamiliar analogue gauges

Figure 6-53. Diamond DA 40 PCATD Glass and Analogue Cockpits

Source: (Johnson, 2011, pp.10-11) -Comparison between the effectiveness of Visual Flight Rules Training utilising Analog and Glass Cockpits. School of Aviation_Palmerston North, Massey University. Masters.

Safety has become a focus of attention with the introduction of new cockpit technology. The National Transportation Safety Board (NTSB) in the USA commissioned a study to determine whether light fixed-wing aircraft equipped with glass cockpits such as the Garmin G1000 and Avidyne PFD4000 were actually safer than legacy cockpits (MItchell, 2010). The study examined the accident rates of over 8,000 light piston-powered fixed-wing aircraft manufactured between 2002 and 2008. The data indicated that light single-engine aircraft equipped with glass cockpit displays had lower total accident rates but higher fatal accident rates than similar aircraft equipped with conventional analogue instruments. Accidents involving glass cockpit aircraft were associated with personal/business flights, longer flights, instrument flight plans, and single-pilot operations.

Accidents involving conventional analogue cockpit aircraft were associated with instructional flights, shorter flights, and two-pilot operations. The NTSB (2010) review of accidents involving light aircraft equipped with glass cockpits found that pilots' experiences and training in conventional cockpits did not prepare them sufficiently to operate the complex glass cockpits being installed in light aircraft. In addition, the lack of training and information provided to pilots about glass cockpit systems led to misunderstandings and incorrect interpretation of system failures. Therefore, the report recommended that there was a need for new training procedures and tools to ensure that pilots were adequately prepared to safely operate aircraft equipped with glass cockpit avionics (NTSB, 2010). Relatively low cost replication of the glass cockpit was initially thought to be virtually impossible due to the lack of suitable low cost technology and limited access to proprietary software source code. However, the appearance of new commercially available software tools and versatile graphic display systems has quickly removed most technological barriers (Flight 1 Aviation Technologies, 2011).

6.6.2.3 PCATDs and Motion Platform Systems

Over the last twenty years and across various types of flight simulation devices that replicate helicopter, commercial transport, and military aircraft, it has been reported that motion improves in-simulator flight performance and increases the realism of pilot behaviour (ALPA, 2007; Burki-Cohen, et al., 2003a; Burki-Cohen, et al., 1998; Martin, 1981; Vaden & Hall, 2005).

Caro (1979) identified motion cues as manoeuvre and disturbance motion cues Researchers have determined that flight control tasks can be classified into two general types: manoeuvre task and disturbance task management (Bowen, Oakley, & Barnett, 2006). Manoeuvre tasks (sometimes called tracking tasks) are the domain of the visual system, which uses visual rate feedback. In VFR conditions, the pilot will rely on visual scenery detail to provide feedback for controlling the aircraft. Unlike manoeuvre tasks, disturbance management tasks use vestibular feedback. Disturbance tasks are not caused by pilot control input but rather external forces, such as turbulence or engine malfunctions, that are exerted on an aircraft. Disturbance cues are not expected by the pilot and therefore play a significantly different role in overall aircraft control tasks (Bowen, et al., 2006).

Although professional pilots still strongly support the use of full motion simulators for training there has been significant research which contradicts this assumption (Burki-Cohen, et al., 1998). A number of researchers found that switching off the motion platform on high fidelity simulators, did not have a significant effect on training transfer. These first training transfer studies conducted seem to indicate that flight control skills associated with disturbance cues do not necessarily transfer to the aircraft (Burki-Cohen, et al., 1998; Roscoe, 1991). This controversial finding was supported by Longridge, Bürki-Cohen, Go, & Kendra, (2001) who investigated the role of motion in a FAA qualified Level C turboprop simulator on recurrent airline pilot qualification. Their quasi-transfer study did not find a significant effect of simulator motion on pilot control-input behaviour or pilot-vehicle performance during evaluation, training, or transfer to the simulator with motion as a replacement for the aircraft. The presence or absence of motion also had no significant effect on the pilots' evaluation of the simulator.

One critical finding that contradicted Longridge et al's (2001) s research results was a follow up quasi-transfer study conducted by Burki-Cohen, Go, Chung, Schroeder, Jacobs & Longridge (2003b) using an enhanced motion flight simulator. A NASA Level D 747 simulator was used and the lateral acceleration and heave cues were enhanced by increasing the cue magnitude. Forty Boeing 747-400 Captains and First Officers volunteered as participants. Each participant was assigned to either a Motion or No-Motion group. The Motion group was evaluated and trained with motion. The No-Motion group was evaluated and trained without motion. Both groups were then subsequently tested for transfer of training in the flight simulator with motion as a replacement for the aircraft. The four manoeuvres that they were trained and evaluated on were two engine failures with continued take-off and two engine-out landing manoeuvres with weather. All failures involved an outboard engine.

The results of the study indicated that many effects of motion emerged that had not been demonstrated in other simulators. This indicated that use of motion in a simulator might be justified in some circumstances. There was limited support for the use of motion for currency training but strong support for its use in evaluating pilot performance in the simulator. Nevertheless, although motion was relevant for pilot evaluation there was still no beneficial effect on training transfer when using motion.

6.6.3 The Development of a Diamond DA 40 (Glass Cockpit) IFR/VFR Procedural Trainer PCATD for Pilot Training

The Diamond DA 40 - Garmin 1000 equipped cockpit was a major upgrade to more conventional flight instruments and avionics found in traditional general aviation aircraft. The glass flight deck presents flight instrumentation, navigation, weather, terrain, traffic, and engine data on large-format high-resolution displays (see Appendix O1). This sophisticated cockpit can provide trainee pilots with a high level of situational awareness, flight monitoring capability, and system management skills. A significant challenge in developing this PCATD was the requirement to emulate the Garmin 1000 and its myriad of integrated systems.

These included an Attitude and Heading Reference System (AHRS), GFC 700 Autopilot, Terrain Awareness and Warning System (TAWS), and Traffic Information Services. To assist in achieving a wide range of research outputs, the PCATD design had to include a motion platform; multi-screen visual displays, a fully functional cockpit, and a networked instructor station. New high-resolution terrain is continually being developed by other NZ based scenery developers not only for recreational use but to assist with VFR training. For example, navigation training in PCATDs requires synthetic terrain to be as accurate as possible (see Appendix P1 & P2). A commercially available FTD with similar capabilities could cost between $600,000 to $1 million NZ dollars (Diamond Simulation, 2012). The aim was to use low cost techniques in its design similar to those used in PCATD projects 1-4. These would include re-using the MSFS software engine, COTS hardware, & software, and modular software and hardware interfaces that were developed in-house.

A design proposal and budget was presented to a university research allocations committee. Consequently, a project grant of $80 000 was approved in 2010. However, this level of funding only represented 10% of the cost of a comparable FTD with similar capabilities in terms of glass cockpit replication, motion system, and graphic display technology. The Diamond aircraft manufacturing company now has its own simulator division. This division has a distinct advantage in that it can build FTDs with hardware such as aircraft-specific panel, seats, controls, pedals, throttles, etc. from its original Diamond DA40 aircraft inventory.

Despite the ease of manufacture, the cost of its flight simulators is still too high for most small to medium flight training operators (Diamond Simulation, 2012). PCATD project funding at this level provided significant challenges in developing all of the necessary sub-systems and communication protocols to simulate the Diamond PCATD effectively. These techniques included the adaptation of new graphic display technologies coupled with new USB capable flight instrument technologies.

A new version of MSFS, FSX Gold Acceleration, was required to drive the graphic displays and the complex glass-cockpit systems. In addition, the motion platform demanded a significant amount of computer processing resources. This meant the motion system had to be controlled by the instructor station computer that also required a high-speed network hub to link to the main PCATD computer. The Diamond DA 40 design represented significant innovation in PCATD technological development both in capability, and complexity (see Appendix O2).

The combination of new hardware and software technologies surpassed many of the innovative design techniques used in the Stage 4 PCATD development. The PCATD project was completed in November 2010, and CAA certification was achieved in May 2011 (CAANZ SOA, 2011) (see Appendix H1). One of the main principles in the design of the PCATD was to utilise COTS hardware and software wherever possible, and minimise the use of proprietary equipment. Another strategy to reduce development costs was to use a variety of inexpensive open source software programs and modify them to achieve the project requirements. Due to the complexity of the software sub-systems used for replication of the glass cockpit, a number of software protocols had to be coded by the project team because equivalent software was not commercially available.

6.6.4 PCATD Motion Platform Technology

Disturbance motion is one of the strongest arguments for the continued use of simulator motion. The US Airline Pilots Association argued that motion is required because the vestibular system provides the most powerful and rapidly sensed cue for self-motion control (ALPA, 2007). Hexapod systems are the main motion systems used for high fidelity commercial simulators. They commonly use six linear actuators that are driven independently. This type of system can achieve six degrees of freedom (bank, yaw pitch, surge sway and heave) of movement and is very realistic (van Roy, 2010). However, these simulation systems are exceedingly complex and expensive to purchase and maintain (see Appendix Q1).

To make the motion platform move, each axis needs some type of driving actuator. These actuators can be rotational or linear. In the case of the linear type, the actuators' travel has to be long enough to produce the required axis movement, and provide sufficient force to move the platform weight quickly. A rapid response, accuracy, reliability, and safety are all critical to the effectiveness of a motion platform. The hardware/software interface has to be robust in order to interact with a PC-based simulator. Hydraulic actuators are mostly used where strong forces are required to move a heavy simulator cabin. They are normally found only on high fidelity full flight simulators, as they require complex oil pump and driving systems. Another method is to use compressed-air powered actuators. These pneumatic actuators are easier to manufacture, and can be successfully used for simulators that have lighter loads. However, with pneumatic actuators it is more difficult to control their thrust and position accurately (FAA, 1996)

Electrical linear actuators are becoming increasingly popular for driving motion platforms. They can be used for low to medium loads, can be accurately controlled, and interfacing is relatively easy, by using an analogue electric driving system with positional feedback via a servo control system to a digital controller (van Roy, 2010). A low cost alternative that provides two degrees of freedom of movement (bank & pitch) is a tilting platform with a central support or universal joint and usually driven by electrical actuators

This platform can support a reasonably large mass (e.g. 1000 kg). One limitation is that the pilot trainees are relatively high in relation to the pivoting point. This high center of gravity means that the weight distribution of simulator cockpit is critical otherwise components in the motion platform could easily be overstressed. Also the pilot trainees will experience some secondary forward and sideways movement which may provide additional disturbance cues (van Roy, 2010). The choice of motion platform for the Diamond DA 40 project was constrained by a number of hardware requirements that had to be met. These included:

1. Cost;
2. Availability & Reliability;
3. Compatibility with MSFS;
4. USB interface to PC controller (need for high bandwidth communications);
5. Requirement to support weight of over 350 kg (two trainees, cockpit, and display screens combined).

CKAS Mechatronics Ltd is an Australian based company that manufactures professional quality two degrees of freedom (2DOF) motion platforms specifically targeted at low investment – high performance applications. These platforms provide movement in the pitch axis and the roll axis. These entry-level motion platforms provide an economical solution for motion simulator developers who may not be able to afford a full 6DOF unit. One of the most common applications for the CKAS 2DOF Motion Platforms is for installation into low cost flight simulators for academic and research institutes (CKAS Mechatronics, 2010). The following specifications of the CKAS 2DOF Motion Platform met all the Diamond DA 40 project requirements (see Appendix Q2):

1. Motion Platform can carry a payload of up to 450kg;
2. Eighteen degree swing in either axis;
3. Fully Electric Actuation;
4. USB 2.0 plug and play;
5. Washout filters and acceleration onset cueing algorithms for MSFS;
6. Very high speed update uses 100Hz motion controller for extremely smooth high fidelity response.

The installation of the motion platform was not straightforward and did require additional modifications. These included:

1. Dynamo bolting of platform to concrete floor to stabilise the unit;
2. A special electrical power circuit and separate earthing circuit to protect against electrical actuator current surges;
3. Cockpit modifications to ensure correct weight distribution;
4. Wiring of emergency stop and emergency pause switches;
5. Customised ladders to climb into cockpit;
6. Overhead hand rails to assist with safe entry into the cockpit.

Because of the demand by the simulator software on PC resources, the decision was made to operate the motion simulation software on the flight instructor station PC. This meant the main simulator PC would send complex motion platform operating instructions over the PC network using special interface software (Dowson, 2012). The flight instructor station PC would then drive the motion platform software, which would transmit those flight instructions to the motion platform through a USB interface. This interface was required to ensure high-speed data flow as well as having sufficient bandwidth to cope with the high volumes of data being transmitted. Although only 2DOF the CKAS platform did produce, some subtle secondary movement effects (forward and sideways) which meant its performance compared favourably with a 3DOF platform (CKAS Mechatronics, 2010). The addition of a motion platform to the Diamond PCATD provided another dimension of vestibular disturbance cues for general aviation research and training. The use of motion coupled with a glass cockpit represented a significant increase in PCATD capability when compared to previous projects.

6.6.5 Software Engine –Microsoft Flight Simulator FSX Gold Accelerated

The primary software engine used to drive the PCATD software system was designated as MSFS FSX Gold Accelerated (Purcell, 2009). This version of MSFS was the most powerful version ever released in its thirty-five year franchise, and represented the epitome of low cost flight simulation software. Much to the dismay of the flight simulation fraternity, Microsoft ceased MSFS development after this software release in 2009 (Remo, 2009). However, companies such as Lockheed-Martin acquired the MSFS source code and continued further development with the release of packages such as Prepar3D. One limitation was that this software was focused on military applications training (Lockheed-Martin, 2012). FSX Gold is extremely versatile and contains a number of new Software Development Kits (SDKs). SDKs are critical components as they enable the design of customised software modules by third party software developers. These modules can have a variety of functions and can directly interact with the MSFS SimEngine through dynamic linked libraries that access MSFS internally. Any future upgrades to the Diamond DA 40 PCATD software platform would require the acquisition of the Lockheed-Martin Prepar3D software. This version is the latest development iteration and represents an expanded commercial and military variant of FSX. This is a necessary requirement to protect the intellectual property of the PCATD if it should ever reach a commercial production stage (Microsoft ESP, 2007).

FSX Gold contains an improved 3D global setting that allows flight over polar icecaps, displays true road data, and renders region specific textures. In addition, the maximum altitude was increased from 60,000 ft. to 100,000 ft. The visual database contains over 20 000 airports and an accurate rendition of global scenery with a resolution of 7cm/pixel (Microsoft, 2010). A number of NZ software developers produced high quality locally based NZ terrain and airport scenery. These scenery modules are detailed enough to be used for Visual Flight Rules (VFR) training. One NZ company, Vector Land Class, has utilised sophisticated mapping techniques to produce high-resolution NZ terrain (see Appendix P1). This detailed scenery is accurate enough for cross country navigation and Instrument Flight Rules (IFR) training (Barnes, 2010).

6.6.6 PCATD Graphic Display Technologies

In the Stage 3 PCATD project, low cost multi-screen out-of-cockpit views could only be achieved by networking PCs together and synchronising their displays. This was a workable solution but inefficient. In the Stage 2 helicopter PCATD development project, large data projector screen was used to display the out-of-cockpit views and this was combined with multi-monitor views for the instrument displays. However, the limitations associated with the reduced field of view (FOV) of a single screen were well documented in the Stage 2 ARHT PCATD project.

These limitations were partially addressed in the Stage 3 project by using multi-monitor out-of-cockpit views. The increased field of view markedly improved the peripheral vision for the pilot trainee when using the PCATD. The multi-monitor technology used in the Stage 3 PCATD and Stage 4 PCATD was based on the only COTS hardware available at the time. In the Stage 2 ARHT PCATD, a low cost Matrox Graphic Splitter Module (Analogue) was used to display a synchronised instrument panel display across two LCD monitors without loss in resolution or frame rate (Matrox, 2005).

This first generation technology was not powerful enough to display out-of-the-cockpit views but was capable of updating less complex analogue instrument displays (Matrox, 2005). In the Stage 4 PCATD project a second generation Matrox Splitter Module (Digital) (Matrox, 2012) was used as it was capable of generating three synchronised out-of-cockpit views (Screen resolution equals 3072 pixels x 768 pixels) as well as drive two separate monitor instrument displays (Screen resolution equals 1024 pixels x 768 pixels). This technology although less than $NZ 1000 per unit could replicate (albeit on a smaller scale) the costly multi-channel display technology commonly found in full flight simulators and high fidelity FTDs (Frasca, 2012b).

Unfortunately, even the latest version of the Matrox Splitter technology was not powerful enough to generate the Stage 5 high-resolution Diamond DA 40 out-of cockpit-window views and drive the more complex Garmin1000 PFD and MFD displays. An alternative low cost solution was required. The solution arrived in 2009, when AMD Radeon began manufacturing low cost multi-display Graphic Processing Units (GPUs) for PCs. They initially released a GPU that could simultaneously drive three graphic displays from the one graphics card with high resolution and with high-speed frame rate. They would subsequently release GPUs that would increase output to six high-resolution displays from one graphics card. This technology called Eyefinity and fulfils three distinct functions:

1. Hardware support for three or more monitors attached to a single graphics card;

2. Software support to independently configure and run each of those displays;
3. Software support to combine the resolutions of all of those displays into one combined resolution.

A technological innovation of the Eyefinity visual display mode was that the monitors or display screens do not have to be the same size or resolution. This meant the out-of-cockpit- view could be set at the highest resolution whereas the PFD and MFD displays could be displayed at lower resolutions because their digital display information was less complex. A major issue when AMD Radeon developed this technology was that a number of software applications including MSFS were not intrinsically designed to take advantage of this maximised multi-screen display. AMD Radeon solved this problem by developing a Single Large Surface (SLS) mode that is activated when an AMD Eyefinity technology display group is created. SLS mode combines the resolutions of all the connected displays, and then essentially “tricks” the Windows operating system into believing that there is one display with a large combined resolution (AMD Radeon Graphics, 2012).

In the case of the main PC that drives the Diamond DA 40 PCATD, the Windows operating system channels this composite display information to Microsoft Flight Simulator FSX. The Diamond DA 40 PCATD was the first device developed in NZ to use three large screen displays with Radeon Eyefinity technology combined with Simkits Garmin 100 hardware and a CKAS motion platform (see Appendix O3). The use of recently developed COTS hardware and software technologies from a variety of manufacturers coupled with the Windows 7 operating system and a new version of MSFS introduced a high level of risk in terms of project integration. The probability of encountering hardware and software incompatibility issues was almost a certainty However, the robust software tools and expertise developed in previous projects ensured that these incompatibilities did not cause insurmountable problems and solutions were eventually found.

The graphic display specifications required for the Diamond Da 40 project was as follows:

1. A GPU that could drive three 37 inch LCD displays for out- of-cockpit views at an overall resolution exceeding 5760 pixels x 1024 pixels;

2. A GPU that could display the dual PFD and MFD screens at a resolution of 1024 pixels x 768 pixels;
3. A GPU that could display dual screens (Moving Map & Flight Parameters) at a resolution of 1024 pixels x 768 pixels.

The GPU equipment used to fulfill these requirements was as follows:

1. Two Radeon 5600 GPUs were used to drive the triple out-of-cockpit views and dual Garmin glass cockpit displays;
2. One Radeon 5400 GPU was used to drive the Instructor station dual display.

The GPU hardware used in this PCATD project proved its capability and in some cases exceeded specifications in terms of resolution levels displayed in the out of cockpit views.

6.6.7 Garmin 1000 (G1000) Simulation

The ability to simulate the real-world Garmin 1000 Glass Cockpit in a cost effective way was a major challenge. Two recent technological developments of COTS hardware and software were effectively utilised in the development of the Diamond DA 40 PCATD. The Simkits Garmin TRC1000 is a replica (100% size scale) of a real Garmin G1000 Glass Cockpit System as found in the Diamond DA 40 aircraft. The display functionality is supported by FSX and Rockwell–Martin Prepar3D software. The hardware is produced from high quality ABS plastic using plastic injection moulding, and high quality electronics. A complete TRC1000 system includes two main displays and one Audio Panel. The high-resolution screens of the PFD and MFD displays are connected to additional video ports on the flight simulator PC. The MFD and PFD displays each have a single USB connection, which provides a data highway through which the control of the knobs, pushbuttons, SD Card interfaces and the video information is channelled (Simkits, 2011). These devices were found to be reliable although there were initially problems with first generation video controllers embedded in the devices. With an upgrade to second-generation video controllers, the units have performed flawlessly over the last eighteen months of operation. With more increased utilisation for research and training, they require continual assessment of their reliability under repeated-use training. Nevertheless, the cost of these units plus the audio controller was approximately a third of the cost of a commercial Diamond DA 40 Desktop procedural trainer without flight controls and autopilot functions only (Garmin, 2008). Flight1 Aviation Technologies has recently developed a G1000 Student Simulator software package that interfaces with FSX (see Appendix R1 & R2). The Flight1 Tech G1000 Student Simulator was developed for real-world flight training in provides an immersive training experience. It also seamlessly integrates with the Simkits TRC 1000 Garmin hardware. Another advantage of Flight 1 Garmin software is that it is a stand-alone application that can be operated remotely through a PC-based network (Flight 1 Aviation Technologies, 2011)

6.6.7.1 Automatic Flight Control System (AFCS)

The use of glass cockpit technology to train ab-initio pilots has resulted in major changes to the training syllabus and the introduction of scenario-based training, which is designed to better equip pilot trainees for future careers in the airlines (Kasemtanakul, 2009). What has surprised flight instructors who have taught legacy flight skills based on the MBT model, has been the high degree of automation at the ab-initio level for glass cockpit training (FAA, 2006). Many older flight instructors have had difficulties in mastering the new technology and then had the added challenge of instructing new students on how to use it (Goldston, 2010). Using a low cost glass cockpit PCATD with Garmin 1000 functionality was found to have high training value for pilots who were transitioning on to glass cockpit aircraft (Flight 1 Aviation Technologies, 2012b).

The Flight 1 Aviation Technologies Garmin 1000 Student (G1000) Simulator software included an accurate simulation of the Garmin GFC 700 digital Automatic Flight Control System (AFCS) that realistically models the Flight Director and Autopilot. Other software features include flight recording and playback, system failures and extensive flight planning. The stand-alone Failure Generator application was connected to the G1000 Student Simulator software on the Instructor Station PC and provided a flight instructor with the ability to fail specific components of the G1000 display (including Airspeed, Altitude, Heading, Attitude, Vertical Speed, Nav Radio, Com Radio, Transponder, and RAIM). When failed, each component displayed appropriate failure flags and/or visual indications. The MFD software includes Waypoint, Navigation, and nearest page groups.

Also, Direct To, Flight Plan, and Procedure functionality. Flight plans can be created, saved, and loaded (Flight 1 Aviation Technologies, 2011).

This third party software can emulate almost 80-90% of the full functionality of the original Garmin 1000 PFD and MFD technology and yet costs less than $NZ 400. This is a significant achievement when we consider that Garmin 1000 software technology has only been developed after many years of research and capital investment and its source code is proprietary. Nevertheless, there were limitations with the first generation release of the software (60% functionality) and it required a number of bug fixes and maintenance upgrades to solve interface problems (Flight 1 Aviation Technologies, 2011). It took almost six months of constant feedback with the software developers combined with onsite testing before the software was stable enough to be used operationally in the PCATD (J, Rhoads, Personal Communication, 10 Jan 2011). One major limitation remained that needed to be addressed was the lack of New Zealand Airport Instrument Approaches in the Fight 1 Technologies G1000 Student Simulator database.

6.6.7.2 NZ Instrument Approaches

The G1000 Student Simulator features an updatable worldwide navigation database. This was provided by Navigraph, a company that provides a monthly updated Aeronautical Information Regulation and Control (AIRAC) cycle of instrument approach data. This Navigraph database mirrors the Jeppesen database (real- world Garmin database) to a certain extent. The Navigraph contains 12,500 airports of which 3,751 airports contain complete instrument approaches. The cost of the Navigraph yearly subscription is surprisingly low at only 20 Euro (13 AIRAC cycles), and although the database is expanding each year it may take considerable time before it models all 49,000 of the world’s airports (Navigraph, 2011). One serious limitation of the Navigraph database was the lack of accurate instrument approach data for New Zealand airports, Auckland, Wellington, Christchurch, Dunedin, and Palmerston North. This has meant that instrument approach data had to be hand coded for local airports such as Ohakea, Wanganui, Paraparaumu, Masterton, Dannevirke, and Hawera. In addition, most of the New Zealand instrument approaches that existed in the database required major updates, especially

VOR/DME approaches. For example, Palmerton North (NZPM) has one of the most complex VOR/DME approaches in the country and the Navigraph approach data had to be extensively revised. A comparison between the two databases indicates how the approach transitions and final approaches are constructed. Despite the clarity of the Navigraph database format the development of customised instrument approaches was not straightforward. The G1000 software utilises the FSX autopilot engine and there are some well-known issues with this autopilot engine. One example is the NZPM RNAV approach (see Fig. 6-54). In this particular approach, the G1000 software Auto Pilot (AP) will instigate a right hand turn into terrain after the missed approach point MATP1. There is a flaw in the FSX auto pilot engine that sometimes appears when completing a 180-degree turn. In this special case, the AP will turn the wrong way even though the correct turn direction is specified in the Navigraph database. This kind of flaw can undermine the training of an instrument approach procedure and therefore practical solutions had to be found.

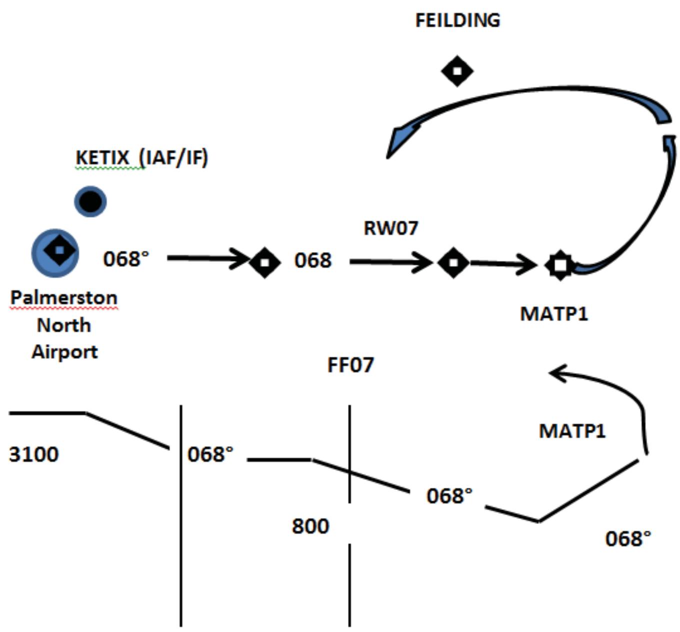

Figure 6-54. Example of RNAV Approach (Simplified Facsimile)

Source: (AIP NZ, 2010)- NZPM RNAV Plate-http://www.aip.net.nz

In this scenario a precisely placed dummy waypoint to the left of the missed approach point MATP1, will coax the AP engine to turn left back to the KETIX waypoint and the holding pattern. Nevertheless, this is a compromise, as the dummy waypoint will be listed in the MFD approach list. A unique labelling system by which the student pilot can recognise such dummy waypoints in the PCATD will help them to differentiate virtual waypoints from those that exist in the real-world Garmin database (Garmin, 2011). This should not be a major issue as the Jeppesen database (used in real-world Garmin flight decks) has a number of discrepancies in relation to NZ instrument approaches. A certain amount of latitude is required when comparing the official airways approach plates with the two different databases, Jeppesen & Navigraph (Navigraph, 2011).

More research is required in this area to find the best match for simulated instrument approaches on the PCATD and real-world practice. Other areas that limit the complexity of IFR/VFR instrument approaches that can be displayed relate to the type of Transition Approach legs the G1000 software can process. A current limitation is that the following legs are not supported by the Flight 1 Aviation G1000 software (Flight 1 Aviation Technologies, 2012a). However, innovative coding meant that most of the following functions were emulated accurately (Garmin, 2011):.

1. CD – Course to a DME distance;
2. CI – Course to an intercept;
3. CR – Course to a radial;
4. VA – Heading vector to an altitude;
5. VD – Heading vector to DME distance;
6. VI – Heading vector to an intercept;
7. VM – Heading vector to manual termination;
8. VR – Heading vector to a radial.

Despite these limitations, virtually all Standard Instrument Departure (SID), STAR, RNAV, ILS, NDB, and VOR/DME approaches were accurately simulated with a combination of G1000 software and a modified Navigraph database file designed for specific NZ airport instrument approaches.

6.6.8 Evaluation of the Diamond DA 40 PCATD

The evaluation of the Diamond DA 40 PCATD was driven by four primary objectives. Could the PCATD be used effectively for?

1. Research;
2. VFR training using a glass cockpit configuration;
3. IFR training, using a glass cockpit configuration;
4. Certification by CAANZ of a glass cockpit PCATD for IFR/VFR training.

CAANZ certification meant that the glass cockpit PCATD could become an approved device to provide cost effective instrument rating assessment, and instrument recency training. Certification would also provide external validation of the PCATD's overall fidelity for IFR/VFR training as well as aviation industry recognition of its fitness for purpose. Twelve pilots were selected to evaluate the Diamond DA 40 PCATD. Five were flight instructors and seven were flight trainees. These participants were working or training in the local area and did not have to travel too far to participate in the evaluation. A representative range of flight experience was achieved by including junior (C Category) and senior flight instructors (B Category), students with a CPL or a PPL, and ab-initio students. The aim was to use pilots with differing experience levels in the evaluation phase to obtain a broad perspective of the PCATD's performance and effectiveness. The demographic composition of the twelve pilots that completed the evaluation was as follows (see Table 6-31):

1. Ten pilots were male & two were female;
2. The pilots were aged between 18-65 years old;
3. The total aircraft flight hours of each pilot ranged from 25-5000 hours with a Mean of 933.7 hours (Median 162.5hours);
4. Five pilots were flight instructors (two B CATs, and three C CATs), one had a CPL, four had a PPL, and two were ab-initio students.

The participants were required to practice and then evaluate eleven IFR/VFR tasks in the Diamond DA 40 PCATD. These training tasks were chosen as the most relevant for the Diamond DA 40 from a reference list of seventy tasks outlined in a similar study by (Johnson & Stewart II, 2005).

Table 6-31. Evaluation of Diamond DA 40 PCATD – Aircraft & PCATD Training Experience

Total Flight Hours Experience	Diamond DA 40 Flight Hours	Diamond DA 40 Instrument Flight Time	PCATD Hours Experience Total
0 (50 hours<)	0 (10 hours<)	3 (10 hours<)	0 (0.5 hours<)
6 (50-250 hours)	6 (10-250hours)	7 (10-30 hours)	9 (0.5- 10 hours)
6 (>250 hours)	6 (>250 hours)	2 (>30 hours)	3 (>10 hours)

These were classified by a senior flight instructor as the most relevant tasks as they encompassed a range of basic IFR/VFR and advanced IFR/VFR tasks that closely matched the training requirements for Scenario Based Training (FAA, 2006). More tasks could have been added but taking into consideration the time constraints of the project and evaluation, data on eleven primary tasks would provide an accurate picture of the effectiveness of the PCATD. In the second phase, the pilots were required to answer questions that related more to the user interface and fidelity of the PCATD. Any comments and observations could be recorded by the pilots on the questionnaire as they completed their evaluations

6.6.8.1 Cognitive Walkthrough

The pilots were required to practice the eleven IFR/VFR procedural tasks using a Diamond DA 40 flight model on the PCATD. There was no specific time limit but they could practice each IFR/VFR procedure until they completed it successfully. At the end of each of each of the eleven assessments of the IFR/VFR tasks, the pilots had to rate the following statement:

Practicing the particular IFR/VFR flight procedures or manoeuvres in the Diamond DA 40 PCATD can improve proficiency in the aircraft

The Likert scale was used and provided a range of responses that measured the respondent's intensity of feeling concerning the statement. A decision was made to adopt a five point scale which was used in previous studies (Johnson & Stewart II, 2005; Stewart, 2001). The response/evaluation categories were *Strongly Disagree* - rated 0, *Moderately Disagree* - rated 1, *Neutral* – rated 2, *Moderately Agree* - rated 3, *Strongly Agree* - rated 4. One non-scoring category was included, *Unable to Rate* - where the evaluator had not reached a sufficient level of expertise to rate the task or was unavailable for that task.

6.6.8.2 Heuristic Evaluation

This was followed by a heuristic evaluation where the participants had to rate seven statements that related to the user interface and level of fidelity of the PCATD. The seventh statement was open-ended and allowed them to note concerns or suggestions about the PCATD, and how the design could be improved. The statements (except 7) were closed and could only be answered with one of the five Likert responses:

1. The functional fidelity of the flight controls on the PCATD are at a high enough level to complete the IFR/VFR flight tasks;
2. The resolution of the NZ terrain & runways depicted in the PCATD is accurate enough for IFR/VFR flight training;
3. The flight model characteristics of the Diamond DA 40 depicted in the PCATD are realistic;
4. The instrument panel (glass cockpit configuration) depicted in the PCATD is realistic enough to conduct effective IFR/VFR training;
5. The cockpit views (outside view) hav2e field of view and terrain resolution at a sufficient level of fidelity for IFR/VFR training;
6. The motion platform increased the effectiveness of IFR/VFR training in the Diamond DA 40 PCATD;
7. Please provide any other feedback on the PCATD (problems, improvements, and limitations).

6.6.9 Results

The results are presented in three parts. First, the results from the practical evaluations of the PCATD in relation to the IFR/VFR tasks are listed. Then descriptive statistics (Mean & Standard Deviation) were used to analyse the eleven task results. Finally, Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha coefficient was calculated for inter rater reliability, and reliability of coding. Krippendorff can also adjust for missing ratings, which was the case. In addition, seven heuristic evaluations of the user interface and fidelity of the PCTAD are described qualitatively. These include comments made by the participants.

6.6.9.1 Diamond DA 40 Task Evaluation

The eleven task evaluations were a mix of IFR (8) and VFR (7) procedures. The results are listed in Table 6-32 and they indicate that the pilots' task evaluation of the effectiveness of the PCATD produced a positive evaluation (above Neutral) for seven of the eleven IFR tasks. All of the VFR tasks had a positive evaluation. This indicated that fidelity issues related to completing VFR tasks effectively in the Stage 5 PCATD had markedly improved from the VFR related evaluations of the Stage 1-4 PCATDs. The responses to the statements in part two of the evaluation form provided some insight. The respondents stated that there was significant improvement in areas such as FOV or flight control fidelity.

Table 6-32. Pilot Ratings for Practical Evaluation of IFR VFR Tasks in Diamond DA 40 PCATD

IFR/VFR Flight Tasks (Basic & Advanced)	No. of Participants	Mean (0-4)	Standard Deviation
Instrument Scan (IFR/VFR)-Basic	12	2.6	0.7
Airspeed Control (IFR/VFR)-Basic	12	2.1	0.67
Altitude Control (IFR/VFR)-Basic	12	2.1	0.67
Navigation Rehearsal(VFR)-Adv	12	2.3	0.62
Circuits (VFR)-Adv	12	2.3	0.45
Overhead Rejoin Patterns (VFR)-Adv	12	2.4	0.51
Procedural Turns (IFR/VFR)-Adv	12	2.2	0.72
Intercept Glide Slope (IFR)-Adv	8	1.6	1.1
Missed Approach (IFR)-Adv	8	1.5	1.1
SID Rehearsal (IFR)-Adv	7	1.6	1.1
STAR Rehearsal (IFR)-Adv	7	1.6	1.1

Finally, Krippendorff's alpha was used to measure inter-rater reliability and agreement. Krippendorff's alpha coefficient was calculated for inter rater reliability, and reliability of coding. Krippendorff can also adjust for missing ratings, which was the case here. The value of α = 0.0541 indicates there was only a very small level of agreement between participants (see Table 6-33). This result may have been due to incomplete data and the small number of raters.

Table 6-33. Stage 2 PCATD Krippendorff's Alpha Coefficient (95% Confidence Interval)

	Alpha	LL95%CI	UL95%CI	Tasks	Raters
Ordinal	.0541	-0.0499	0.1542	**11**	**7-12**

6.6.9.2 Heuristic Evaluation

The participants in this evaluation were requested to provide a heuristic evaluation of the Diamond DA 40 PCATD and its suitability as a flight-training device for IFR/VFR tasks. The evaluation consisted of the following questions:

1. The functional fidelity of the flight controls on the PCATD is at a high enough level to complete the IFR/VFR flight tasks?

Three participants Moderately Disagree, five were Neutral, and four Moderately Agree.

The feedback from the participants was that the PCATD stick controls were quite sensitive. However, the flight controls did have friction screws and bungee cables, which did provide some measure of resistance. The lack of flight control feedback required the participants to concentrate and focus more and execute manoeuvres with increased fine motor control. However many of the experienced pilots stated that the Diamond DA 40 (being a low-drag, light composite aircraft has very sensitive flight controls and therefore the PCATD was quite realistic in this regard. In addition, the glass cockpit provided high a level of automation and many IFR ab-initio manoeuvres are executed by using the Flight Director or Autopilot

2. The resolution of the NZ terrain & runways depicted in the PCATD are accurate for IFR/VFR flight training?

One participant Moderately Disagrees, two were Neutral, six Moderately Agree, and three Strongly Agree.

The majority of the participants found the depiction of terrain in the PCATD very realistic and superior to that found in most commercially available FTDs in NZ. The high-resolution NZ scenery developed for the PCATD produced extremely accurate (10 metres horizontal) terrain with photorealistic 3D objects (runways, roads, buildings, etc.). This meant VFR tasks such as navigation rehearsal could be practiced intensively and the terrain depicted in the PCATD was a good match of real NZ terrain.

3. *The flight model characteristics of the Diamond DA 40 depicted in the PCATD are realistic?*

Two participants Moderately Disagree, four were Neutral, five Moderately Agree, and one Strongly Agrees.

Overall, there was a positive response in regards to the evaluation of the flight characteristics of the Diamond DA 40 PCATD. The flight model did accurately reflect the Diamond performance characteristics (e.g. rate of climb, cruise speed, and rate of descent). However, one problem was the floating effect over the runway. The real aircraft has a high lift to drag ration as well as low profile-drag so it can be difficult to lose height quickly. This effect was exaggerated in the flight model software and resulted in the virtual aircraft failing to land on occasions. The flight model was then adjusted to minimise this adverse aerodynamic effect. Two participants stated that the overall feel of the flight model still needed some improvement.

4. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, of fidelity to complete the IFR/VFR maneuvers?

Two participants Moderately Disagree, four were Neutral, and six Moderately Agree.

Ten participants found the external cockpit display of the PCATD equal in quality to a commercially available FTD external display. The three 37 inch screens displayed a field of view of 120-150 degrees.

The FOV range provided the pilots with a good peripheral vision. It was more than adequate to provide the necessary visual cues, elevation cues, and spatial orientations, necessary to complete the VFR manoeuvres.

5. The instrument panel depicted in the PCATD is realistic enough to conduct effective IFR/VFR training?

Three participants Moderately Disagree, three were Neutral, and six Moderately Agree.

A crucial design feature was that the replica PFD/MFD in the PCATD glass cockpit was the same size as the real Garmin units (Simkits, 2011). In addition, the software provided a high level of situational awareness as well as emulating the complex functions of these devices. Overall, the participants were pleasantly surprised at the high level of functionality of the PCATD glass cockpit. Although it should be noted that the software could only replicate 80-90 % of the full functionality of the real Diamond DA 40 glass cockpit. The cockpit instrument panel was a critical component of the PCATD project as it was vital that the participants could rehearse complex glass-cockpit procedures as realistically as possible.

6. The motion platform increased the effectiveness of IFR/VFR training in the Diamond DA 40 PCATD?

Two participants were Neutral, and four participants Moderately Agree.

Due to time constraints and the additional setup time required for motion platform operation, only six of the twelve participants used the motion platform while completed the IFR/VFR tasks. The participants were very positive about the use of motion and indicated that the vestibular cues they experienced intensified and reinforced the visual cues presented by the multi-screen displays. Two of the participants had experienced a full flight simulator with motion before. For the other four participants this was the first time they had experienced a motion platform, and although tentative at first, they quickly adapted to the presence of vestibular and disturbance cues. They commented often that the vestibular feedback definitely helped them with performing the IFR/VFR maneuvers. This was also a critical component of the PCATD project because if the pilots had perceived the platform motion as unrealistic then the device would have had very little training value. A minor criticism was the sensitivity and turbulence experienced on the motion platform when landing the PCATD, However after some adjustment to the washout algorithms that drive the axes of movement, this effect was minimised. Although this was a subjective evaluation by a small sample of pilots, the results indicate that there is scope for further investigation into the effectiveness of training general aviation IFR/VFR tasks on a PCATD equipped with a motion platform.

7. Please provide any other feedback on the PCATD (problems, improvements, limitations etc.).

Suggestions were made to adjust the environment where the PCATD was located. This was the first time this type of feedback had been received. The recommendation was to paint the ceiling and surrounding walls in matt black to reduce external cues when using the motion platform. The PCATD does have the limitation of an open cockpit, which can allow too many external cues. A simple detachable cockpit surround was constructed but was quite heavy and took some time to install and most pilots did not use it. The startup procedure of the PCATD requires a number of steps that have to be performed in sequence by the pilot. This could be improved on by automating the startup operation with the use of software batch files.

6.6.9.3 NZ Civil Aviation Certification of the Diamond DA 40 PCATD

Apart from general aviation IFR/VFR glass cockpit training, an additional goal of the Stage 5 project was to develop the Diamond DA 40 PCATD to a level of fidelity that would achieve FSD2 Synthetic Flight Trainer certification (CASA, 2006). An external evaluation of the PCATD required an application to be submitted to CAANZ to audit and certify the device (CAANZ, 2011a).

Certification of the Diamond DA 40 PCATD would enable trainee pilots to log up to 10 hours of glass-cockpit flight simulator time towards the requirements of an instrument rating. In addition, pilots could use the PCATD for instrument currency training to complete one approach procedure of the three required to be completed in the aircraft every three months. CAANZ certification with its emphasis on aviation safety also provides an internationally recognised validation of the overall fidelity, engineering quality, and measure of training effectiveness of the PCATD. NZ CAA certification can also have an influence on future commercial PCATD development, as many flight .training schools will only purchase certified FTDs or PCATDs to reduce flying hours and serve as training aids. Certified PCATDs can be used to provide effective IFR/VFR procedural training but due to certification can the training time can be logged towards instrument ratings (CAA, 2006). A comparison of the economic benefits of using the PCATD is outlined in Table 6-34.

Table 6-34. Cost Comparison of Operating Aircraft vs. PCATD

Cost of Aircraft Operation	Cost of FTD Operation	Cost of PCATD Operation
Massey Aviation Diamond DA40 Single Engine - $380 per hour DA 42 Twin Engine -$560 (F. Sharp, personal communication, 12 Nov, 2012)	Diamond Simulation DA 40 /42 FTD (Fixed Base) Capital Cost $NZ 1 million Operating Cost $N200 per hour	Massey Aviation Diamond DA 40 PCATD (Motion) Capital Cost - $80 000 Operating Cost $80 per hour

Two general aviation flight simulator SMEs were employed by CAANZ to conduct all flight simulator certification and flight simulator audits in NZ. An application was lodged in 2011 to apply for CAANZ IFR/VFR certification for the Diamond DA 40 PCATD. The audit team travelled to Massey University School of Aviation Flight Centre and conducted a certification audit on the PCATD and relevant training documentation (J, Parker, personal communication, 27 April 2011). The PCATD audit checklist, which was quite extensive, is outlined in Appendix I. It includes assessment of the PCATD's physical structure, instrument systems, radio navigation systems, operating characteristics, instructor station, pilot station, handling characteristics, and documentation (CASA, 2002). PCATDs are designated by CAANZ as Synthetic Flight Trainers (SFT) and can be approved for the purpose of accumulating aeronautical experience under provisions contained in AC 61-17 "Pilot Licences & Ratings - Instrument Ratings" (CAANZ, 2011d). They are classified as flight procedure trainers and may be approved for the purposes of:

1. Accumulating instrument ground time;

2. Maintaining instrument rating currency;
3. Maintaining instrument approach currency;
4. Completion of an instrument rating annual competency demonstration;
5. Completion of the demonstration required for an additional make and model of a Global Navigation Satellite System (GNSS) navigation aid.

The authorisations that were issued for this Synthetic Flight Trainer are outlined in Appendix H2 (CAANZ, 2007a). These authorisations meant the Stage 5 PCATD as of significant training and economic value to the Massey Aviation flight school. Other criteria that had to be met for CAANZ certification included:

1. A regular maintenance schedule with a recording system for defects,
2. Flight instructor SFT authorisations;
3. Flight examiner authorisations;
4. A SFT training syllabus;
5. A SFT Standard Operation Procedures Manual;
6. Emergencies Procedures Manual.

The first generation Garmin replica software had reduced functionality (60%) and this is why the NZ CAA instrument rating allocation was set to a maximum of ten hours instead of twenty hours. Subsequent to that first CAANZ certification, the software has been upgraded as well as the NZ instrument approaches. A renewal audit is due in 2013. With the latest installation of third generation software, functionality is now closer to 80-90% and approval will be sought to increase instrument-rating time on the PCATD to twenty hours. This project represents a milestone in PCATD development in NZ. It is the first NZ developed Garmin based glass cockpit PCATD to be CAANZ certified for IFR/VFR flight training. This is recognition of the continuous improvement and progress achieved in five stages of PCATD project development. It also demonstrates the versatility of the PCATD development in relation to the different training aircraft that were replicated and the range of training tasks that had to be simulated.

Formal CAANZ certification was achieved on 16 May 2011. Achieving CAANZ certification was an external benchmark that demonstrates innovative PCATD development can achieve the required levels of fidelity and conformity normally reserved for expensive commercial FTDs (CAANZ SOA, 2011). The Massey University School of Aviation (SOA) is also committed to assist other flight training schools with their training programmes by helping them develop customised PCATDs specifically designed for the NZ flight-training environment.

6.6.10 Discussion

This was an evaluation of the Diamond DA 40 PCATD used for IFR/VFR flight training at a university aviation school. The aviation school required a PCATD to assist with IFR ratings assessment, instrument currency training, and VFR training for its new Diamond DA 40 and 42 aircraft fleet. The evaluation was in two parts. The first part was a behavioural evaluation (cognitive walkthrough) where the pilots performed a flight task at least once but preferably twice before providing a rating. The second part was a heuristic evaluation of the PCATD's fidelity and user interface. A representative sample of Massey Aviation pilots with a broad range of flight experience performed the evaluations.

6.6.10.1 Task Evaluations

Overall, there was positive feedback from the pilots who performed the IFR/VFR task assessments on the Diamond DA 40 PCATD. The evaluators rated the VFR tasks more highly than the IFR tasks assessments. The average rating of VFR tasks was Neutral to Moderately Agree. The average rating of advanced IFR tasks was Moderately Disagree to Neutral. The pilot evaluators justified these assessments by stating that the depiction of high-resolution terrain and the wide field of view of the PCATD were particularly helpful when rehearsing VFR tasks manoeuvres. The execution of these tasks depends on extensive out-of- cockpit views that provide good peripheral vision. The lower assessment rating of IFR task capability in the PCATD was directly related to the complexity of the real Garmin 1000 PFD and MFD. There were no major issues with basic instrument flying procedures undertaken on the PCATD, as they were very similar to the aircraft. However, as instrument approach procedures became more complex, glass cockpit PCATD procedures began to diverge from the procedures in the real aircraft system.

Unfortunately, in a low cost PCATD, it was not economic to develop software code to replicate complex functions such as fuel management and satellite synchronisation. The compromise in the fidelity of this glass-cockpit simulation was to replicate as realistically as possible the critical functions in the Garmin 1000 instrument panel and emulate the basic operational procedures of other less critical functions. This compromise in low cost PCATD development is supported by studies indicating that high levels of fidelity might not be necessary for successful task transfer (Macchiarella, et al., 2006; McDermott, 2005b).

Several flight instructors expressed concerns that flight instruction in the PCATD had become too focused on learning to operate the Garmin 1000 technology and less on learning or rehearsing skills to fly the aircraft. Currently, the teaching of complex Garmin panel functions takes up a large portion of the instruction time. The Diamond DA 40 composite aircraft has a long wingspan, low-drag fuselage, complex engine management, and sophisticated automation systems. This means that ab-initio pilots must contend with an aircraft that may have unusual flight characteristics and high cockpit workload. Successful instruction in IFR/VFR tasks and manoeuvres means that any non-critical distractions caused by glass panels must be recognised and eliminated (Greenway, 2010).

6.6.10.2 Heuristic Evaluation

The heuristic evaluation completed by the selected pilots established that the main limitation in PCATD fidelity that required improvement was the sensitivity and feedback of the flight controls.

In the case of the Diamond DA 40 aircraft, the flight controls differ from conventional aircraft such as the Pipers Cherokee, which normally have a yoke flight control. The Diamond uses a military type long-handle joystick stick that protrudes through the seat. The sticks are directly linked to potentiometers that connect directly to a Haagstrom Keyboard/Joystick Interface Board. To compensate for the lack of force feedback in the joysticks the rudder pedals were dampened with small air shock absorbers. In addition, bungees and a friction screw were attached to the control column to provide some sensation of control resistance. Upgraded software drivers and filters were also used to increase response times to control inputs in the MSFS program.

It should be emphasised that the primary aim of this PCATD was procedural task training and due to the relatively low fidelity of the flight controls, successful transfer of psychomotor flying skills was achievable but limited in scope. The lack of force feedback in flight controls has been a recurring issue in all of the PCATD projects. In the past, the only solution available was to use high cost servo-controlled flight controls, which were not financially viable for a low cost PCATD. As mentioned previously, technological development of components for low cost flight simulators continues to accelerate. The development in the United Kingdom of new hydraulic joystick technology (retail cost = $NZ 1700 per unit) with force feedback is a paradigm shift that could solve the last major obstacle in the development of low cost PCATD flight controls (Paccus, 2012).

Despite the limitations, successfully completing VFR training tasks with the current flight control technology was achievable for the average pilot trainee. This was also confirmed by the NZ CAA audit team (J, Parker, personal communication, 24 April 2011). However, it required ab-initio pilots to stay focused and expend more effort in fine motor control. Flight instructors indicated this additional effort may not be a disadvantage but could actually improve pilots IFR/VFR task skills in the aircraft. The recent commercial development of motion platforms costing $NZ 20 000 - $NZ 50 000, has now made it possible to incorporate motion into relatively low cost FTDs and PCATDs. The cost of these platforms is a small fraction of the overall cost of legacy hydraulic motion platforms used in high fidelity full flight simulators.

More research is required to investigate the training effectiveness of these devices in general aviation training. Virtually all motion platform research has focused on recency training in full flight simulators operated by airline companies (ALPA, 2007; Bowen, et al., 2006; Burki-Cohen, et al., 1998). Although a number of studies question the effectiveness of motion in flight-training task transfer, the general feedback from the participants in this study was that motion was beneficial to training performance. Their perception was that motion did enhance their learning by reinforcing the visual cues during IFR/VFR manoeuvres with vestibular (disturbance) cues. The PCATD's Eyefinity graphic display received favourable reviews from the evaluators. The three screens were the largest LCD screens used on any of the five PCATD projects (see Appendix O2).

The high resolution and clarity of these displays exceed the graphic specifications of many commercial FTDs AMD Radeon Graphics, 2012). The field of view exceeds 120 degrees and can reach 150 degrees when incorporated with the MSFS zoom display function. One major limitation of the LCD flat screens is their limited depth of field but new technology in the form of LCD and LED with 3D vision is now commercially available. The only disadvantage of 3D vision is the requirement to wear compatible 3D glasses. A few prototype 3D vision displays that incorporated multiple LCD screens linked together using Eyefinity or similar technology have been developed for extreme gaming enthusiasts (Gamescom, 2012). They are currently classified as a proof of concept. It may be some time before multiple LCD 3D vision capable screens linked together in a 3x1 or 6x2 array to form a large composite image will be available (Gamescom, 2012). In addition, some investigation will be required to see if 3D vision using multiple monitors will be compatible with PCATD applications such as MSFS. However, when the technology matures this may solve the lack of depth-of-field in LCD based visual displays used in PCATDs. It could also render the cumbersome and expensive collimated screens obsolete, which are currently used in full flight simulators.

The Stage 5 PCATD research project was an opportunity to determine the feasibility of developing effective low cost PCATD technology that incorporated a complex glass cockpit configuration coupled with a 2DOF motion platform (see Appendix O3). It has also allowed the end user the opportunity to evaluate the training effectiveness of a glass cockpit PCATD and determine how best it can be incorporated into the new scenario based flight-training curriculum.

In terms of research capability, one graduate student completed a study on automation complacency (Weng, 2010) and a second post graduate student completed a comparative study on the training effectiveness of conventional cockpits versus glass cockpits (Johnson, 2011). It is hoped that the Diamond PCATD will continue to be a valuable research and flight training aid for the SOA both now, and in the future.

Chapter 7. Overall Discussion

The development of PCATDs and their increased acquisition by flight training organisations has raised questions regarding their efficacy. The questions that have been investigated in this study are as follows:

1. How much fidelity in a PCATD is needed for effective transfer of training of IFR/VFR skills to the operational aircraft?
2. How much of the IFR /VFR task can be effectively simulated in a PCATD?
3. How does the effectiveness of a PCATD compare to a Civil Aviation Authority Certified FTD when used specifically for training VFR tasks?

This chapter discusses these questions within the context of the five PCATD projects, which form the basis of this study.

7.1 Introduction

Historically, the development of high fidelity flight simulators and flight-simulation training programmes was an expensive and highly technical undertaking. This was especially true if the simulator had to provide high-resolution graphic displays for out-of-cockpit-views, replica cockpit environments, and motion platforms for disturbance cues. However, rapid advances in computer and electronic interface based technology supported by new and more powerful software tools have created a significant paradigm shift in simulation development (Garvey, 2006). Recent improvements in CPU/GPU processor speed, video memory/bandwidth, and RAM density have meant that PCs now have the potential to drive high fidelity simulators (Grady, 2003) . In the future, the manufacture of high fidelity flight simulation of the cockpit environment and the external virtual world will no longer be monopolised by well-established simulator manufacturers (Adams, 2008). At the same time, low cost flight simulation is proliferating around the world as evidenced by new simulators being developed by small startup companies, research institutions, and home hobbyists (PFC, 2012).

The development of PC-based Aviation Training Devices (PCATDs) and Desktop Part Task Trainers, have a number of advantages:

1. Increasing availability and range of low cost PCATD compatible hardware;
2. Increasing availability and range of low cost PCATD software & software development tools;
3. The use of modular components with industry standard interfaces and communication protocols for constructing PCATDS;
4. Using PCATDs for training instead of FTDS and FFSs has meant a significant reduction in acquisition and maintenance costs.

However, the fundamental question still to be answered is whether relatively low cost PCATDs can provide the same training benefits that high fidelity simulators or actual aircraft deliver. It has been established that flight simulators of all types produce some degree of positive transfer (Caro, 1988). It has also been documented in a number of studies that there is a positive transfer between PCATDs and the aircraft. (Dennis & Harris, 1998; Koonce & Bramble, 1998; McDermott, 2005b; Talleur, et al., 2003; Taylor, et al., 1999; Taylor, et al., 2004). However, the main aim of these training transfer studies was investigating the efficacy of PCATDs for instrument flight rules training. By comparison, there has been far less empirical research on the effectiveness of PCATDs in VFR skills training, a major focus of this study. In addition, this study has also investigated the most efficient and effective approach towards the development of PCATDs. Compromises had to be made in the design of the five PCATDs to achieve the best balance of fidelity, training effectiveness, and cost of development.

7.2 How much fidelity is needed in a PCATD for effective transfer of training of IFR/VFR skills to the aircraft?

Fidelity is a measure of the degree to which a simulator can replicate the real world. It has been viewed as a crucial variable in the design of flight simulation devices. The aviation training industry has always contended that high levels of fidelity are necessary to achieve high levels of training transfer to the aircraft (Noble, 2002).In addition, the aviation industry has invested heavily in simulation, more than in most other industries where safety is paramount. Unfortunately, the demand for higher levels of fidelity to increase the realism of simulation has increased costs, and reduced access to flight simulators. In most instances, only large flight schools are able to afford a high fidelity simulator, which represents a significant capital investment in operating and maintaining the device. However, these schools have also found that very high levels of technologically driven fidelity can be detrimental in terms of cost and time relative to the levels of training transfer required. Beckman (1998) noted that high-fidelity simulators may even detract from training effectiveness for new trainee pilots as they become overwhelmed by the complex learning environment. Furthermore, little substantive research has been undertaken to establish just how much fidelity is required for effective training. Sometimes flight simulation devices that are perceived to fly quite poorly can still be effective training devices (Stewart II, et al., 1999). The development of low cost, low fidelity PCATDs has been supported by a number of studies that found high levels fidelity were not necessary for effective transfer of training (Alessandro, 2008; Koonce & Bramble, 1998; Stewart II, et al., 2001)

Two categories of fidelity were evaluated within the five PCATD projects, physical fidelity, and functional fidelity. Physical fidelity describes equipment cues that provide a duplication of the look and feel of the aircraft. These include static and dynamic characteristics, which include types of flight controls and visual displays. Functional fidelity describes environmental cues such as cockpit environment and motion through the environment (Alexander, et al., 2005). The physical fidelity of PCATD components that were evaluated across the projects were:

1. Flight Controls;
2. Depiction of Terrain and 3D Scenery Objects;
3. Dynamic Flight Model;
4. Instrument Panel;
5. Visual Display.

7.2.1 Flight Control Fidelity

7.2.1.1 Finding 1

A PCATD with low fidelity flight controls has similar levels of transfer of training as an FTD or PCATD with high fidelity flight controls.

Large differences between the flight control fidelity of the PCATD and the FTD used in the Stage 4 PCATD comparative study had no significant effect on the VFR performance across eight tasks. Additionally, irrespective of which simulator was being used, students believed that they had improved their VFR performance skills. This outcome was confirmed when no significant differences were found between students trained on the PCATD with low fidelity flight controls and those trained using high fidelity controls on the FTD, on a post-test assessment conducted on the FTD. Admittedly, the PCATD was more difficult to fly without the force feedback feature of the FTD flight controls. Although the VFR exercises were completed successfully, evaluators agreed that greater concentration was needed, and more fine motor control was required when executing VFR manoeuvres in the PCATD. They suggested that the extra effort and attention expended on using the low fidelity controls in the PCATD would translate into improved psychomotor skills when faced with a difficult situation in the aircraft such as flying through turbulence. This finding confirmed the value of using low fidelity controls, as high fidelity flight controls can add considerably to the overall cost of the PCATD, but may not necessarily improve transfer of training.

Flight control fidelity relates to the subjective feel of how the simulated aircraft responds to the flight controls (Williams, 2006). The most common criticism that pilots make about flight simulators is that the flight controls do not feel right and even the most high fidelity FTD or FFS may not escape this criticism. To improve the feel, simulator manufacturers have developed high fidelity flight controls that are very expensive and incorporate complex, dynamic control loading or force feedback sub-systems. McHale (2009) noted that the aviation industry and military aviation in particular, are still expending considerable effort and money into increasing high fidelity and realism in simulators in the in the hope that it will increase positive transfer. Phillip Perey, technical director at CAE in

Montreal, stated that, "Fidelity in simulators is 20 times what it was only 10 years ago"(Mchale, 2009, p. 2). The flight controls used in the Stage 4 PCATD were relatively low fidelity compared to those used in the FTD. The Precision Flight Controls (PFC) used in the PCATD consisted of a potentiometer driven control yoke, throttle quadrant, and rudders (PFC, 2004), while the Frasca TruFlite FTD used a proprietary yoke, throttle quadrant and rudder pedals. The Frasca high fidelity flight controls were approximately twenty times the cost of the low fidelity PFC flight controls. The major difference between the flight controls was that the Frasca flight controls used a dynamic control loading system that featured high-torque electric motors to generate the forces that pilots encounter (Frasca, 2012a).

Other studies have examined the role of flight control fidelity. McDermott (2005a) found no difference in IFR task performance between the FTD (high fidelity controls) trained group and the PCATD (low fidelity controls) trained group. He did note however, that the PCATD's flight controls did not have the same physical, sensory input, and tactile feel of an actual aircraft, and commented that "new pilots have to get used to flying the simulator" (p.56).

Two studies compared PCATD, FTD, and aircraft transfer of training in IFR task performance (Talleur, et al., 2003; Taylor, et al., 1999) and demonstrated successful transfer of training, suggesting further support for the notion that low fidelity flight controls can have the same transfer of training effect as high fidelity controls in IFR tasks. However, relatively little work until now has explored transfer of learning in VFR tasks.

Atkins, Landsdowne, Pfister, & Provost, (2002) examined VFR task training and used a low fidelity fixed based synthetic flight trainer to examine the transfer of training between two differing flight control mechanisms; a yoke (higher fidelity) and a joystick, (lower fidelity) on a simulated visual landing approach (VLA). The results indicated that there was a positive transfer of training from the lower fidelity joystick to the higher fidelity yoke, providing some evidence of the ability of a low fidelity PCATD to produce positive transfer effects in VFR task performance. However, this study focused on only one task and one set of controls. The current study, with multiple measures of transfer of training provides substantial empirical evidence of the positive relationship between low fidelity flight controls and VFR task performance. While research has demonstrated the effectiveness of high fidelity controls for transfer of training, the reasons for not using high fidelity controls with features such as force feedback is the high cost of this technology and the complexity of its operation. However, this study demonstrates that there are low cost solutions for improving low fidelity flight controls. Limited force feedback or flight control resistance was achieved by using low cost technologies such as strong graduated springs, bungee cables, compressed air pistons, shock absorbers, and friction screws. Feedback from evaluators indicated that these simple mechanisms were perceived to be surprisingly effective in providing realistic resistance to flight control movements. MSFS compatible software filters significantly improved the response rate and response curve of low fidelity flight controls. The types of low cost feedback technology combined with the flight controls of each project were as follows:

1. Stage 1 RNZAF PCATD-(Joystick, Throttle)-Springs, Software filters;
2. Stage 2 ARHT PCATD-(Cyclic, Collective, Twist Throttle, Anti-torque Pedals)-Springs, Compressed air pistons, Mechanical modifications, Software filters;
3. Stage 3 SAV1 PCATD-(Yoke, Throttle, Rudder Pedals)-Springs, Compressed air pistons, Software filters;
4. Stage 4 SAV2 PCATD-(Yoke, Throttle, Rudder Pedals)-Springs, Compressed air pistons, Software filers;
5. Stage 5 Diamond DA 40 PCATD-(Control Stick Throttle, Rudder Pedals)-Bungee cords, Compressed air pistons, Friction Screws, Software filters.

The cost of these augmented flight controls ranged from $300 - $1500 but the evaluation ratings were similar irrespective of price indicating that cost was not a major factor. Instructor and student feedback indicated that:

1. Augmentation had a positive influence on the subjective evaluations of the flight controls;
2. Augmentation of flight controls assisted with transfer of training.

While there was no objective evidence to support these views, pilot feedback indicated that it increased their confidence in the fidelity of the device. Electric Control Loading (ECL) is an advanced force feedback design that simulates the forces acting on flight controls in both static and dynamic conditions. It provides realistic levels of resistance and inertia to the flight controls through the entire range of the aircraft's flight envelope (Frasca, 2012a). This technology is usually found on high fidelity FTDs (Elite, 2012d) and full flight simulators but is rarely found on PCATDs due to its cost and complexity. This study investigated cost-effective alternatives to ECL for PCATDs. Most low fidelity flight controls are designed with separate control sticks or yokes, throttle quadrants, and rudder pedals. A distinguishing characteristic of these low fidelity flight controls is they lack ECL, and can only provide basic tactile response by using internal passive spring loading. Therefore, all of these flight controls were augmented with a combination of low cost technologies such as bungee cords, compressed air pistons, friction screws, and software filters.

This lack of ECL was a major limitation in the Stage 2 Helicopter PCATD project, which was the most difficult challenge in terms of flight control fidelity. Even though other PCATD projects had demonstrated that high levels of flight control fidelity were not required for successful task transfer, helicopter flight controls required special attention. Helicopter flight controls are extremely complex and function in completely different ways to fixed wing flight controls. Real helicopter controls are cross-linked and non-centering so it is difficult to replicate the correct feel of the controls in a low cost PCATD.

In the Stage 2 Helicopter PCATD project, the evaluators agreed that the PCATD combined with augmented flight controls achieved the level of fidelity required for pilots to complete the IFR/VFR tasks successfully. This was reflected in the task evaluations, which were uniformly positive. In addition, in the Stage 4 PCATD comparative study, the students achieved acceptable VFR task performance levels on the PCATD equivalent to those students trained on the FTD. However, the instructors' evaluations still indicated a preference for higher levels of fidelity on the Stage 4 PCATD than objective evaluations indicated it needed to be. The deeply ingrained beliefs of the experienced pilots and instructors appear to be difficult to change.

Helicopter flight-control fidelity has been investigated by others. For example, Johnson and Stewart's (2005) recruited sixteen instructor pilots and students to evaluate the ability of a commercial micro-simulator PCATD to support seventy one specific flight tasks which were part of the core flight tasks in a helicopter training curriculum. The helicopter PCATD had a set of Flight Link helicopter controls (Cyclic, Collective, anti-Torque Pedals). These passive spring-loaded flight controls did not incorporate force feedback or augmentation and there were a number of criticisms of the controls including complaints about lack of force feedback and trim. In fact, the perceived lack of flight control fidelity was one of the factors that the evaluators cited as to why the PCATD was best suited for IFR training and not VFR training of manoeuvres such as hovering. However, the overall task evaluation of the PCATD was positive, with the students rating the PCATD higher than instructors did.

A study by Stewart II, Weiler, Bonham, & Johnson (2001) compared the effectiveness in the transfer of training of IFR skills between a high fidelity motion based Synthetic Flight Training System (SFTS) with a low cost Frasca PCATD. The motion simulator used hydraulic force feedback flight controls whereas the PCATD used passive spring-loaded flight controls, augmented with a powered trim system for cyclic pitch and roll controls. The overall task evaluation of the PCATD was positive. The findings from check ride scores demonstrated that ab-initio students could improve their instrument-phase flight skills in the low cost PCATD. However, with this study there were some criticisms of the flight controls, especially the cyclic control.

Reaching an acceptable level of fidelity in the flight controls was a critical aspect of the Stage 2 Helicopter PCATD design. The pilots' perception of the helicopter PCATD as a credible training device was dependent on a number of factors, but flight control fidelity was a high priority. Additionally, without some level of augmentation of the ARHT helicopter flight controls it would have been difficult for the pilots to use the PCATD effectively for advanced VFR exercises such as hovering and autorotation. This was an issue recognised by them, and they made high levels of conformity and fidelity of flight controls mandatory for certification. The augmentation of standard COTS flight controls with low cost force feedback or control resistance technologies only increased the level of fidelity by a small amount, but this slight increase in fidelity had a significant influence on whether or not the PCATD could be an effective device for advanced VFR skills training.

7.2.1.2 Finding 2

Low fidelity flight controls can be configured on low cost PCATDs to meet the standards of civil aviation authority certification.

Achieving CAANZ certification provided strong evidence that relatively low fidelity flight controls installed into low cost PCATDs can achieve the levels of accuracy and control response necessary to substitute for some training time in an aircraft. At the beginning of the Stage 1-5 PCATD projects, no NZ made PCATD had achieved certification because the NZ aviation training industry had been wholly dependent on foreign manufacturers to supply their flight simulation training requirements. However, NZ has an unusual aviation-training environment with a large range of geographical features in a small area, and rapidly changing weather patterns. There was a need for low cost flight simulation devices that could achieve certification, and replicate the NZ aviation-training environment accurately.

The requirements for PCATD certification in NZ are based on the guidelines outlined in some detail in the CASA FSD2 “Operational Requirements For Approved Synthetic Trainers” (CASA, 2002). Most regulatory bodies require the flight controls to have a specified static and dynamic feel to achieve the desired approval levels. In terms of fidelity, certification assessments do not specifically mention force feedback for flight controls but this is implied in the three assessment criteria that are examined in relation to the effect of flight controls; operation and control are conventional, secondary effects are conventional, and control forces are acceptable. The assessment of the Stage 2 Helicopter PCATD controls was even more stringent within the certification process. This was due to the requirement of the PCATD to simulate correctly, the primary effects of controls, secondary effects of controls, and advanced helicopter aerodynamics. All of the correct flight control effects and responses had to be accurately simulated in conjunction with simulator’s flight models (CAANZ ARHT, 2010). A significant feature of certification is that the fidelity of one component such as the flight controls cannot be treated in isolation. A common test conducted by CAANZ auditors was to compare the fidelity of the flight controls in relation to the fidelity of the flight model, instrument panel, and visual display system of the PCATD (CAANZ ARHT, 2010).

A different issue concerning flight controls emerged in the Stage 5 Diamond DA 40 PCATD project development, and was related to the glass cockpit system. In the glass cockpit, there was a high degree of automation, and flight controls had many multifunction switches built into them, for example, the trim and autopilot switches on the control stick, and the Go-Around (GA) switch on the throttle. When the GA switch is activated it specifically manages the missed approach procedure by raising the nose of the aircraft and increasing the power automatically (Garmin, 2011). The simulation of these complex interrelated functions was pushing the boundaries for low cost simulation. As glass cockpits become more functionally complex, and sophisticated in their multi-tiered operation, the more difficult it becomes to produce low cost PCATDs designed to replicate them. Even with the successful certification of the Stage 5 Diamond DA 40 PCATD, it only replicates eighty-five per cent of the functionality of a real Garmin 1000 cockpit.

Fortunately, the remaining fifteen per cent of the functionality encompasses a suite of esoteric functions that are rarely used by a pilot trainee, and are not cost effective to replicate in the PCATD. Since the CAANZ certification of the Stage 2 Helicopter PCATD and Stage 5 Diamond DA 40 PCATD projects only three other PCATDs made in NZ have achieved certification (two fixed wing, one helicopter), however the helicopter was later decommissioned (Pacific Simulators, 2012; Ruscool Electronics, 2011). Two commercial PCATD brands, built by overseas companies are now operating in NZ (Elite, 2010; Redbird, 2010).

7.2.1.3 Finding 3

Student pilots make more positive and more accurate evaluations of simulator effectiveness than experienced flight instructors.

Students in this study consistently rated the effectiveness of low fidelity PCATDs more highly than did their more experienced flight instructors, and their evaluations closely matched those of the objective evaluations. This suggests that they found the simpler training environment more conducive to learning and less confusing. The nature of this experience may make student pilots more aware of the actual training benefits of the different training devices than their instructors. Support for this argument is suggested by Macfarlane (1997) who proposed the concept of instructional fidelity, which he defined as "the degree to which the instruction or the instructional system is able to effectively transfer new skills to the pilot" (p. 64). He suggested that training benefits were increased by using simulators that limited or removed distracting information and allowed the student to focus their attention on vital cues.

This finding supports those of Johnson and Stewart II (2005) in which instructors and students were asked to evaluate a helicopter PCATD in terms of how well it supported the seventy one specific Initial Entry Rotary-Wing (IERW) Common Core flight tasks. Students evaluated the effectiveness of the simulator more highly than their instructors did. Similarly, in a comparative study, Stewart II, Barker, Weiler, Bonham, and Johnson (2001) found that student pilots favoured a Frasca PCATD over a high fidelity motion simulator. Conversely the instructor pilots in the same study, although acknowledging the training potential of the PCATD, rated the motion simulator higher. A simulator appears to be evaluated more favourably by flight instructors if it is high fidelity, based on the assumption that a high fidelity simulator must be more effective than a low or moderate fidelity simulator. However, immersion in a high fidelity environment does not necessarily constitute effective training. High fidelity may cause information overload, provide conflicting data, and distract the pilot trainee from performing basic tasks (Macfarlane, 1997). The compelling argument is that the evaluation of fidelity should be determined by the cognitive and behavioural requirements of the flight-training task and not the pre-conceptions of SMEs and instructors on acceptable levels of fidelity. The level of fidelity built into the simulator should be determined by the level needed to support learning on the tasks that will be trained using the device (Macfarlane, 1997; Salas, et al., 1998).

A large proportion of experienced pilots not only underestimated the training effectiveness of low fidelity simulators, they were also critical of their value. Despite evidence in this study of the effectiveness of PCATDs in VFR skill training, many experienced evaluators continued to make critical comments about the PCATD's flight controls. These included, "the flight controls are too sensitive," "it doesn't feel right," and "sometimes the aircraft is too hard to control." Nevertheless, about half of experienced flight instructors expressed cautious optimism in their evaluations. For example, there was agreement that the Diamond DA 40 PCATD had sensitive flight controls and that this accurately reflected the real controls in the low-drag, light composite aircraft. Other research has found that highly critical evaluations of PCATDs are a common phenomenon. One explanation for this critical attitude to low fidelity is offered by Salas, Bowers, and Rhodenizer (1998) who argued that when most simulators are evaluated subjectively by SMEs, flight instructors or trainees, personal bias can arise. Subjective measures such as questionnaires and ratings can focus on the evaluator's preconceptions of the required level of fidelity, and less on its training effectiveness.

7.2.2 Depiction of Terrain and 3D Scenery Objects

7.2.2.1 Finding 4

High fidelity scenery detail is required for instrument landing approaches and VFR cross-country navigation training.

Results from student performance on two training scenarios undertaken on the PCATDs, indicated that high fidelity was required to complete the requisite VFR tasks. Students were unable to complete the tasks successfully without high levels of fidelity. The first instance was to practice unexpected transitions between instrument and visual flights rules. The second situation occurred when specific landmarks had to be identified for navigation purposes. In aircraft flying, spatial disorientation can occur following an unexpected move from visual into instrument meteorological conditions due to rapidly changing weather, or poor decisions. Spatial disorientation is a common cause of fatal accidents in visual flight rules rated pilots (Tropper, Kallus, & Boucsein, 2009). Similarly, on the PCATD, simulated flight from instrument to visual flight rules, and vice versa can cause students to experience a level of spatial and geographic disorientation. In MSFS, the default scenery displays most minor airports as a runway or runways with the correct length and orientation combined with some randomly placed 3D generic building objects. With airports in close proximity, this can cause some confusion, and it is difficult for the pilot trainee to recognise distinctive features of a simulated airport when they are so generic. The use of high fidelity terrain in the form of photorealistic runways and buildings can make airports extremely realistic, and easy to recognise even with poor visibility settings. The usual visibility setting for IFR training on the PCATD was 1-5 nautical miles, which matched real world conditions. What is also essential is the depiction of 3D objects adjacent to the airport such as roads, animated windsocks, fence lines, and trees, all of which assist the trainees in gauging the correct descent profiles on the final approach.

There was a similar requirement for high fidelity terrain in the PCATD for cross-country VFR navigation rehearsal. When conducting VFR navigational exercises in aircraft flying, critical turning points and VFR reporting points may be as simple as a bend in the river, an intersection of roads, or even a prominent building. The requirement for high fidelity terrain for navigation training is on a scale far greater than just coverage of the airport and local area. Simulated cross-country navigation exercises may require travelling over sparsely populated terrain over significant distances. Therefore, terrain such as mountain ranges, rivers, coastlines, roads, and railway lines across the whole country, has to be rendered accurately and in high fidelity. In addition, 3D replication of power lines, factories, and small townships are required as pilots use these landmarks to check for drift or as waypoints while en route.

In the transition from IFR to VFR and navigation rehearsal tasks on the PCATD, visual cues were required so that students could orientate themselves to the geographical terrain and locate their correct position visually. These cues had to be in the form of computer-generated landmarks or terrain features that accurately match features on a map or real world observation. High fidelity terrain features were added to the PCATD’s visual database because synthetic landscapes generated by MSFS can often be just a series of duplicate texture tiles representing features such as farmland, desert, or cityscapes (Szofran, 2006).

Locating a unique 3D object location in this type of synthetic terrain is not possible unless it is specifically modelled. The type of IFR/VFR task determines the level of terrain fidelity required. Many tasks such as instrument flying in cloud, and flying procedural turns do not require high levels of terrain fidelity as these tasks can be completed with less assistance from visual cues presented by the terrain. High fidelity depiction of terrain has only recently been achieved with the low cost display systems commonly found in PCATDs (VectorLandClass, 2011). In the past, many simulator systems struggled to display even moderate levels of terrain fidelity. This is due to high quality computer generated imagery (CGI) placing heavy demands upon the system resources of PC-based systems. New moderately priced PCs equipped with multi-core central processing units (CPUs) coupled with powerful graphic processing units (GPUs) can now depict synthetic terrain at extremely high resolutions, and combine it with photorealistic scenery (Corn, 2009).

Despite these technological advances, low cost PCATD systems have to manage computer resources carefully to simulate sub systems such as scenery detail, flight modelling, instrument panel updates, and weather at an optimum level. Even the most sophisticated PC can be brought to a standstill if visual realism and scenery detail levels are set too high. MSFS has many parameter settings to optimise variables such as scenery detail, visibility, and cloud density. PCATD flights can be preconfigured to adjust scenery detail to the training requirement, thereby freeing up vital computer resources for other tasks.

The dominant assumption in simulation training has been that increased scene detail increases transfer of training (Alexander, et al., 2005; Buckland, 1981; Goss, 1991; Mulder, et al., 2000). However, research challenges this assumption. Lintern, Roscoe, Koonce, and Segal (1990) established that high fidelity in terms of increasing the scene detail did not increase training effectiveness. This finding was supported by Nobel (2002) who also found that low levels of scene detail did not necessarily inhibit training transfer. These studies seem to suggest that in some cases low scene detail was better for transfer than moderate or high scene detail. The underlying reason being that high fidelity visual information could overwhelm or confuse the student.

The key was to restrict the visual scenery information to a level that provides just enough information so that the student can still fly the aircraft in a stable manner. However, the current study provides evidence that higher fidelity is beneficial for specific tasks such as cross-country, circuits, and overhead rejoins manoeuvres. This position extends Proctor, Panko, and Donovan's (2004) that found greater levels of terrain fidelity were required to judge speed and distance correctly. Mulder, Pleijsant, van der Vaart, and Wieringen, (2000) also found that high resolution scenery displays can provide an advantage in VFR training transfer performance especially in the landing approach and timing of landing flare. This finding was extended by the current study, which evaluated and measured glide slope performance of pilot trainees who were assisted by high-resolution airfield scenery.

7.2.3 Dynamic Flight Model Fidelity

7.2.3.1 Finding 5

Rapid software prototyping can simplify the development and enhance the accuracy of flight models for PCATDs.

Prototyping refers to the activity of designing or creating software or hardware prototypes, which are incomplete versions, but retaining enough functionality for testing by the user. Prototyping has been found to be particularly effective in the design of human-computer interfaces. Prototyping also requires user involvement, and allows them to interact with a prototype and provide improved and more complete feedback and specifications (Crinnion, 1992). In the current study, one area of PCATD development where software prototyping was found to be particularly advantageous was flight modelling. To create an exact dynamic flight model of a simulated aircraft can take hundreds of person-hours of work. Hundreds of interconnected parameters (e.g. Centre of Gravity, Angle of Attack, Drag coefficients, etc.) all require customisation when developing a realistic flight model of a training aircraft

Due to the length of time needed to develop accurate flight models, this study used the evolutionary prototyping methodology outlined by Crinnion (1992). The first prototype flight model was used in the PCATD by the SMEs even though it had significant flaws. It would seem counter intuitive to use a flawed flight model but it meant that feedback from SMEs could be obtained as quickly as possible, changes made in the software, and then an upgraded flight model could be released for further evaluation.

After the first flight model was evaluated, further development was undertaken and this iterative process continued until final acceptance. Waiting for the completion of a perfect flight model for training would have delayed access to the PCATD and the developer would have lost valuable feedback in the interim stages. It is estimated that using evolutionary prototyping saved an average of 3-6 months of project development time for each of the five projects. In the Stage 2 Helicopter PCATD project, a different technique called incremental prototyping was used. This is where several flight model prototypes were produced, each one focusing on a particular aspect of flight dynamics for testing purposes. Then near the end of the project, the separate flight models were merged into a final flight model design, which encapsulated all of the features of the component flight models. Constant feedback and simulator testing results were elicited from the aircrew to determine the next phase of development of each flight model design. Despite the employment of these rapid prototyping techniques, it was still quite difficult to obtain a flight model that was accurate in every aspect of a particular aircraft's flight dynamics.

The MSFS program was used in all five PCATD projects, and was a software package that demonstrated remarkable versatility. However, it did have limitations in its default software. For example, MSFS does not have advanced helicopter aerodynamics built into its default helicopter flight model, or a suitable technologically advanced aircraft (TAA) flight model. Both of these flight models were required for the PCATD projects that were seeking certification. The solution was to incorporate third party flight modelling software that could replicate advanced aerodynamic features into the project and incrementally improve it in a number of iterative cycles. By utilising this method, a flight model of acceptable fidelity was eventually developed. Other studies that did not use this approach and persevered with the MSFS default flight models encountered difficulties.

In a study by Stewart II, et al (2001) an assessment was made of a proof of concept Frasca helicopter PCATD for instrument training, but there were major issues with the default flight model. There was a tendency to gain, rather than lose altitude in a turn, coupled with inconsistent readings from instruments. No improvements were made to the flight model and these aerodynamic deficiencies almost jeopardised the study. In Johnson and Stewart II (2005), the rating evaluations of the helicopter PCATD's effectiveness in transfer of training of advanced VFR tasks was low. This PCATD used an early version of MSFS that did not have the capability of simulating advanced helicopter aerodynamics. None of the evaluators could achieve VFR exercises such as a stable hover, or steep turns and the flight model did not accurately simulate helicopter flight at low speeds. Other software packages have had slightly more success. Proctor, Bauer, & Lucario (2007) investigated the use of X-Planes in a helicopter PCATD for its capability to model and simulate UH-60 helicopter flight dynamics with air turbulence and varying aircraft weight for the purpose of training. Learning performance was compared with a two DOF motion based helicopter simulator. Although, the PCATD fell well short of the learning objectives achieved in the high fidelity simulator there were no issues identified with the flight model generated in the X-Planes software.

Some of the limitations with the MSFS flight models can be traced back to the internal structure of the software. Most flight-simulator software packages like MSFS use a Newtonian method for simulating the real world performance of an aircraft. X-Planes uses a slightly superior method called computational flow dynamics but it requires a more powerful PC to process the data (Stock, 2007). The technique of rapid software and hardware prototyping has been used before in PCATD development. In a study by Hamilton, McKinley, & Brittain (2005) a rapid prototyping of a multi-aircraft aviation system simulation was developed using a central server, four PCATDs, and MSFS. The aim of the simulation was to train pilots in the new NASA sponsored Small Aircraft Transportation System programme, where pilots self-separate by observing other aircraft near an airport using ADS-B radar surveillance, and a moving-map display, without air-traffic control intervention. The simulation was flown extensively by designated pilots who reported that the multi-aircraft simulation was a realistic portrayal of instrument flight operations. The current study, using five different contexts extends the NASA sponsored study by utilising the time and accuracy benefits of this type of modelling.

7.2.4 Instrument Panel Fidelity

7.2.4.1 Finding 6

Digital flight instrument gauges in a PCATD were as effective as high fidelity FTDs with actual flight instruments or avionics in terms of transfer of training effectiveness.

Despite significant differences in fidelity between instruments in the FTD and PCATD, SMEs from the five PCATD projects commented favourably on the functional fidelity of the PCATD instruments and no adverse effects or issues were detected with their use. Overall, there was a positive evaluation of the effectiveness of the various instrument panels developed for each PCATD. For example, feedback from the participants in the Stage 4 PCATD comparative study indicated satisfaction with the functionality of the low fidelity digital instrument panel compared to the high fidelity gauges on the FTD.

Most legacy full flight simulators and high fidelity FTDs still use actual instruments or high quality replica instruments and avionics copied from the operational aircraft. The most popular low cost technique for PCATDs is to recreate the appearance of each instrument digitally on a computer display (Robinson, et al., 2004). In a high fidelity simulator, that uses actual flight instruments and avionics, only the data input needs to be synthesised (Frasca, 2006a). In a low cost PCATD, both the digital instruments and the data input have to be synthesised. Developing a new digital gauge can be a formidable programming task as most gauges are written in low-level programming languages such as C++. To assist developers, Microsoft has produced an extensive library of ready-made gauges. Also there are large online repositories of custom gauges designated as freeware (Smith, 2012), and third party companies produce a few complex gauges as payware (RealityXP, 2007). For the Stage 1-5 PCATD projects to achieve CAANZ certification, there was no requirement to simulate an exact aircraft type with actual gauges and instruments where digital replicas could be effective substitutes (CAANZ, 2011a).

In the Stage 4 PCATD comparative study, there was a significant difference in the face fidelity of the instrument panels of the PCATD and FTD but virtually no difference in the environment or equipment cues. The participants did not indicate that they suffered any disadvantage in task performance when using the different instrument displays and this interpretation was strengthened by the results of the study. No significant differences were found between participants who trained on the PCATD and those who trained on the FTD. This finding clarifies and adds weight to other studies that have indirectly measured the effectiveness of digital gauges in PCATDs with low fidelity digital instrument panels for transfer of training research (Leland, et al., 2009; McDermott, 2005a; Stewart II, et al., 2001; Talleur, et al., 2003; Taylor, et al., 2004). All of the instrument panels used in these studies had a similar level of physical and functional fidelity when compared to instrument panels developed for the Stage 1-5 PCATD projects. No evidence was found in these studies that the substitution of real instruments with digital instrument displays in low fidelity PCATDs reduced the transfer of training effectiveness of these devices for IFR/VFR skills training.

The use of digital instrument panels has three distinct advantages over legacy panels: cost, portability, and reconfiguration. Digital panels are less costly to build than legacy panels and easier to maintain. Digital panels can be easily transported if required, whereas high fidelity FTDs are often too complex and bulky to be moved. Reconfiguration capability means that PCATDs with digital panels can be easily modified to represent different single engine or twin engine aircraft (Redbird, 2010). In the Stage 4 PCATD comparative study, a technique to make digital displays more realistic was the use of Perspex overlays with instrument cut-outs fixed on the LCD screen displays. These also housed low profile switches, and buttons that were located in the correct position to operate that particular instrument.

Although this is a low cost method, the use of overlays does provide a realistic instrument panel layout when combined with high resolution digital gauges. Most of the pilot trainees' feedback was that the use of digital gauges combined with masked overlays could provide excellent representations of real gauges. In fact, when concentrating on performing flight tasks in the PCATD many indicated that they perceived the high-resolution digital gauges as real. Due to the versatility of this low cost technique it has now been adopted by established FTD manufacturers (Frasca, 2008). The introduction of glass cockpits with computer generated displays for the PFD and MFD have made it even easier in terms of PCATD design, as these displays can be replicated using small LCD screens combined with customised software.

7.2.5 Visual Display Fidelity

7.2.5.1 Finding 7

A field of view of 120 degrees in the visual display is critical for VFR skills training.

The importance of field of view for VFR training cannot be overstated. It provides the critical peripheral visual cues required for fixed wing and rotary wing VFR tasks including hovering, traffic pattern flight, traffic pattern entry/exit, circuits, and autorotation. Without an adequate FOV, a PCATD's out-of-cockpit-views cannot provide sufficient visual fidelity required by pilots to complete VFR maneuvers successfully.

After the completion of the Stage 2 project there was a stronger focus on improving the transfer of training of VFR tasks in future PCATD designs. Through the Stage 2-5 projects the field of view of each PCATD display system was steadily increased, By way of comparison, the field of view was 70° for Stage 1, 90° for Stage 2, and 120° for Stage 3-5. This increase in field of view was mainly driven by the feedback generated from the task performance and the subjective evaluations undertaken by SMEs in each project. It was also influenced by other studies which indicated that limited FOV was a major factor in poor VFR task performance (Roessingh, 2005; Stewart II, et al., 2002). Johnson & Stewart II's (2005) used a PCATD with an FOV of approximately 30°- 60°, all sixteen evaluators commented that the FOV of the PCATD had to be increased, and fourteen of them stated that visual cues for height above ground must also be improved for VFR tasks.

Coupled with the increase in field of view was the rapid improvement in visual display fidelity, without a corresponding increase in cost. This was due to a significant decrease in the cost of PC-based technologies such as graphic display cards and LCD screens as these technologies matured and reached optimum economies of scale in production. Surprisingly as graphic display technologies have become more cost effective, they have also steadily increased in visual resolution and fidelity (AMD Radeon Graphics, 2012).

However, technology often provides a solution but creates a new problem or issue. Field of view is a critical component of visual fidelity but increasing FOV reduces another critical display component, spatial resolution (Padmos & Milders, 1992). Spatial resolution is measured by the number of pixels per inch (PPI) in a display (Keller, et al., 2003). A reduction in spatial resolution reduces the level of detail in the visual display and means that pilot trainees may miss vital visual cues. Therefore, in low cost PCATD design there is a requirement to balance the visual display resources required to maximise FOV, spatial resolution, and object display resolution. Many of the latest FTDs now offer complex curved screen display systems that can generate a field of view of 220° (Frasca, 2012b). This was not a design option on the PCATD projects due to the high cost of this technology but low cost alternatives to increase FOV were found (Proctor, et al., 2007).

Three different software techniques (Zoom, China Hat, Active Camera) were adopted for the use in the PCATD projects to increase the FOV from 120° to an increased range of 220°-360°. Although, these low cost solutions succeeded in increasing FOV they met with only limited success due to issues with visual disorientation, and lack of realism. These optional software features were retained in the PCATDs but many trainees elected not to use them and they continued to operate the PCATD at the default FOV hardware setting of 120°.

Consequently, the development of visual displays in the Stage 1-5 projects was strongly influenced by the VFR training task requirement, rapid advances and reduced costs in PC-based display technology, and a new generation of pilot trainees who were reluctant to train in simulators without comprehensive high-fidelity visual displays. Although most commercial FTDs and PCATDs are used mainly for IFR training (with much less emphasis on visual cues), every device currently available on the market provides some form of visual display (Elite, 2012b; Frasca, 2008). In addition, the allocation of PC graphic processing resources to these display components can be dependent on a number of factors such as the physiology of vision, the type of 3D objects that are being depicted, and how quickly the screen display information has to be updated. The critical components for the visual display include, in order of priority:

1. Screen display size - A large screen size is preferable to provide the trainee with a sense of immersion in the simulation (Alexander, et al., 2005);
2. Field of view – Multi-monitor screens are a low cost method to produce a wide field of view that enables essential peripheral vision cues;
3. Display resolution determines how much detail can be displayed in the depiction of terrain and 3D objects;

4. Spatial resolution relates closely to display resolution in that is calculated by the pixels per inch display. Spatial resolution determines the level of detail in relation to screen size, so increasing screen size will reduce the level of detail.

For example in the Stage 4 PCATD the display screen was expanded to a total horizontal base of 61.72 inches with a 20 inch height (spatial resolution 53 PPI) on the main screen, and 9 inch height on the side screens (spatial resolution - 93PPI), and the display resolution of these screens was set at 1280x1024. This provided an optimised visual display in terms of cost, screen size (immersion), field of view (peripheral vision), and spatial resolution (visual cues). With the reduction in the cost of LCD technology, in the Stage 5 Diamond DA 40 PCATD project the screen size was expanded to a total horizontal base of 96.75 inches with an 18.14 inch height but retained the same spatial and visual resolution as the visual displays in Stage 5. Due to the use of these optimisation techniques, the evaluation of the transfer of training effectiveness of the overall visual display fidelity in the five PCATD projects was increasingly positive as the visual fidelity steadily improved, and field of view and screen size increased. Feedback from the evaluators of the Stage 1-5 projects supported the concept of an optimal display configuration being 100” x 20” screen size, display resolution of 1280 x 1024 or higher and 90-100 PPI.

Several studies have examined the relationship between field of view, spatial resolution and screen size. Keller, Schnell, Lemos, Glaab, & Parrish (2003) used a flight simulator to examine instrument approaches using a fractional factorial design. Some of the factors studied were spatial resolution (80 ppi, 90 ppi, 105 ppi, 120 ppi) and field of view (22°, 30°, 60°, 90°). The results of the investigation suggest that pilot performance is highest and workload is lowest for a spatial resolution of at least 105 pixels per inch (PPI). Increasing the resolution past 105 ppi offered no additional performance benefits. The optimal field of view was 60°. During the cruise phases of flight, a 60°-90° field of view was optimal, whereas during final approach, a 30°-60° field of view was optimal. However, these FOV recommendations related to screen sizes that were very small (6” x 8”), compared to the Stage 4 PCATD display that was thirty six times larger than this. Therefore, with such a small screen, FOV can be relatively small and spatial resolution much higher. In addition, the main flight task in this study was an instrument approach procedure where less emphasis was placed on visual cues. Nevertheless, the study did indicate a minimum acceptable range of FOV of 60°-90°for standard cruise flight. This FOV was used as a suitable benchmark for the visual displays in the Stage 1 and Stage 2 projects.

Comstock, Jones, & Pope (2003) investigated field of view in PCATDs and their findings indicated that that a 90° FOV should adequately support IFR/VFR task training. Proctor, et al (2007) established that the optimum field of view for VFR task training was 120°. Both of these studies placed more emphasis on VFR training and used large screen sizes and therefore were in close agreement, in terms of FOV, with the evaluations of the Stage 3-5 projects.

Most research on PCATD and FTD training has focused on IFR tasks. In the past simulators used for training IFR tasks did not have visual displays at all, as visual cues were not necessary to complete most of these tasks. However, the limited research that has been completed on the use of PCATD s for VFR skills training has suggested that moderate to high fidelity visual displays are essential for transfer of training. This study brings new clarity to the PCATD requirements for VFR tasks. These requirements include maximisation of , levels of scenery detail, terrain resolution, instrument and flight control fidelity, field of vision, display screen size, and spatial resolution.

7.3 How much of the IFR /VFR task can be effectively simulated in a PCATD?

A central issue with developing low cost PCATDs is whether they could be developed to fulfill particular flight-training task requirements and satisfy flight instructor and student expectations within budgetary and resource constraints. Caro (1988) argued that low cost is a relative term. He discussed a research project that compared the training effectiveness of a high fidelity, expensive cockpit procedures trainer with a simple plywood mock-up of the same aircraft. The plywood mock-up had been built at a cost of thirty dollars. This simple training device had functional fidelity in that it could provide the same critical cues for practicing cockpit procedural tasks, as the high fidelity trainer. Caro defined both of these devices as simulators as they were designed to present the cues and responses required for performing procedural tasks in the aircraft. A similar rationale was used for the Stage 3-5 project developments. The low cost alternative was no longer the wooden mock-up but was represented by low cost, low maintenance, PC-based technology systems.

7.3.1.1 Finding 8

Collaboration with flight instructors and pilot trainees in the design and evaluation of the PCATD using action research methodology, improved the versatility, accessibility, and flight-task training effectiveness of the devices.

The Stage 1-5 projects were characterised by the collaborative nature of their development. This resulted in the three low cost PCATDs gaining a high level of acceptance by the pilot trainees as effective flight training devices. For example, the Stage 1 RNZAF PCATD is an integral part of the RNZAF flight-training curriculum. The CAANZ certification of the Stage 2 Helicopter PCATD project meant helicopter-training costs were reduced, which significantly improved the operational readiness of the search and rescue organisation. The Stage 3 and Stage 4 PCATDs were used to provide timely remedial navigation training to pilot trainees at critical points in their training where any additional failures in assessed flights could have resulted in termination. The Stage 5 Diamond DA 40 PCATD provided high value glass-cockpit IFR/VFR training and the opportunity for the trainee to experience motion. This PCATD also offers the researcher a rare opportunity to investigate the effects of motion and its possible effects on task transfer.

The efficacy and adaptability of all of these devices was a product of a cycle of continuous improvement, evaluation, feedback, and testing. A number of recurring themes emerged after the development of each PCATD project. The cycle of modification and evaluation followed a similar pattern. There was the initial feedback from instructors and students on issues concerning fidelity, which dominated the discussion for some time. Once most of the fidelity issues were resolved then their attention inevitably moved towards the task training effectiveness of the PCATD. The analysis of task effectiveness was generally unrelated to fidelity but focused on the human-computer interface. An example was a compromise in a switch placement to assist with the rehearsal of a particular procedure. Finally, once an acceptable level of task effectiveness was achieved then the action research cycle entered a more creative phase. Participants' suggestions tended to be more innovative at this point. For example, an innovative switching circuit arrangement was suggested by a student as a low cost solution to replicate the correct operation of a circuit breaker. Other suggestions have led to the implementation of new projects. For example, using PCATDs for automated scenario based lessons for individual pilot training. Some suggestions were impractical or too costly to implement but were an indication of growing acceptance of the device for training. Aircrew tend to be indifferent towards a training device if it does not work well. However, their enthusiasm can be gauged by the number of suggestions they make as to how the device can be improved. These suggestions also indicated that the evaluators were considering the boundaries of the device and its capabilities. Feedback is critical in the development phase because system designers tend to focus on fidelity and technical improvements but experienced aircrew focus on task effectiveness improvements.

The research cycle of continuous evaluation, modification, and implementation is a two-way communication process and many of the instructors indicated that during the cycle they gained new insight into a particular flight procedure and a more effective way of teaching it using the PCATD. In this type of PCATD development, the flight instructors and students are no longer just passive users of the device but contribute a significant amount of intellectual capital and expertise to its development and improvement.

For most flight-training organisations, the acquisition of a fully certified flight-training device not only requires a significant capital outlay; it also requires a certain level of restructuring of its training programme to use the device effectively. The quality of the device is dependent on the expertise of the manufacturer, and the oversight of the industry regulator who certified it. The flight instructors have no input into the design of the device and usually have to adapt their training style to the idiosyncrasies of the FTD. They have to instruct with the device usually to an advanced level, taking into account its inherent capabilities and limitations, which they may not fully discover for some time.

A survey of NZ flight-training organisations conducted as part of this thesis indicated that many Chief Flight Instructors (CFIs) had difficulty in choosing a device that was best suited to their training needs. This had resulted in an accumulation of devices being used in NZ flight schools, originating from different manufacturers, with different capabilities and fidelity levels. Many of these devices were replaced within a short time after the survey, due to increasing maintenance costs, obsolescence, or even a perceived lack of training effectiveness. Flight training devices contain proprietary hardware and software, and flight instructors and students generally treat it as a turnkey device. Once a FTD was purchased very few changes could be made to improve it or enhance its operation. Upgrading the device was prohibitively expensive. Within a few years, a training curriculum change or the acquisition of new aircraft meant that in some areas of training, the device rapidly approached obsolescence. In addition, the researcher observed that FTDs were being primarily used for economic reasons.

Students normally complete the maximum hours allocated to FTD training that can be credited towards an instrument-rating while under supervision by a flight instructor. Once that was achieved, the device was then virtually ignored by the student. There was very limited use of the FTD by trainees for remedial training or solo IFR/VR task rehearsal. With the development of the Stage 1-5 projects, it was clear that their utilisation was markedly different from the traditional acquisition and use of a high fidelity FTD. Collaboration with flight instructors and pilot trainees in the design and development of the PCATD ensured a certain level of buy-in by them. Buy-in refers to the degree to which a pilot recognises that a device or experience has training value.

The principle is that with higher levels of buy-in the pilot will invest more effort to extract lessons from training, and more effort to transfer those lessons to the real world (Alexander, et al., 2005). In addition, experienced pilots could instantly see what aspects of the design were superfluous, issues that were not always immediately apparent to the designer. For example, one PCATD design had included the development of automated air-traffic control clearances (with synthetic voices) for use in IFR task training. The flight instructors though impressed by the technology had immediately seen flaws in its implementation because the air-traffic control clearances and dialogue can vary tremendously and contain a lot of nuance that is not easy to replicate. This saved many hours of additional work on a feature that may have led to some negative training transfer to the aircraft. Many of these types of suggestions streamlined the design of a PCATD and helped produce a device that was tailored for a particular training programme. This evolutionary process also creates dynamism in flight instruction on the PCATD. Flight instructors and pilot trainees were more willing to experiment with display settings or other parameters on the PCATD. They more willingly participated in "What If" training scenarios to test its capabilities. This type of behaviour was less evident when pilots use high fidelity FTDs. FTDs can be expensive and at large flight training schools there is usually only one or two at most. This means access is limited due to high utilisation, and there is a much more conservative approach when using them. Pilot trainees also were more willing to try different training scenarios on the PCATD and exhibited less timidity when using the device. The PCATD encouraged more exploratory learning which benefited their IFR/VFR skills training.

7.3.1.2 Finding 9

PCATDs were traditionally used primarily for IFR task training but can be effectively used for VFR task training with appropriate visual display enhancements.

The Stage 1-5 PCATD projects demonstrated that with the adoption of low cost visual display technologies, more accurate flight models, and flight control augmentation, effectiveness in training VFR skills could be increased significantly. In comparison, most studies on the use of PCATDs have focused on IFR training and consistently report that PCATDs are best suited to IFR training and have relatively little value for VFR training (Johnson & Stewart II, 2005; Taylor, et al., 2004).. For example, Johnson and Stewart II (2005) produced higher overall effectiveness ratings for advanced IFR tasks than basic VFR tasks. In this study, experienced pilots rated sixteen IFR tasks but only two VFR tasks as best supported by the PCATD. The reasons for the large disparity between the ratings were directly related to the visual fidelity of the PCATD. The PCATD used in Johnson and Stewart II's study had a small screen size and limited peripheral visual cues, which limited its effectiveness for VFR skills training.

In the Stage 1-2 PCATD projects, the emphasis was placed on instrument task training and the evaluation of the device indicated higher effectiveness ratings for IFR tasks than VFR tasks. One of the major influences on the relatively low VFR effectiveness rating was the visual fidelity characteristics of these devices. They both had single screen displays with a limited field of view range of 70°-90°. Although previous research had indicated this field of view range was able to support transfer of training (Keller, et al., 2003), feedback from the evaluators of the Stage 1-2 PCATD projects indicated that they preferred a large field of view as well as bigger screen sizes for VFR training. Larger fields of view are advantageous as they provide greater peripheral cues, but care must be taken as they can distort and reduce the spatial resolution by adding more superfluous information to the limited display space.

Stages 3-5 demonstrated a steady increase in VFR effectiveness ratings as the design of these devices became more focused on the transfer of training of VFR skills. These stages were also characterised by the installation of multi-monitor screens, high-resolution terrain, improved flight models, and a gradual increase in FOV and screen size. The ratings increase confirms work by Reeves & Nass (1996) who found that images on a large screen (90" or more) are remembered more than those in a smaller screen, and receive more positive evaluations of the visual display content. They also found large screen sizes could immerse the users within the virtual environment more effectively, which improved performance. However, they also found that large screen sizes had the potential to over-stimulate viewers to the point that they may miss relevant visual cues.

This finding supports those of Stewart, Dohme, & Nullmeye (2002) who asserted that training in a low-cost VFR simulators could substitute for in-aircraft training with no significant loss in trainee performance, provided the out-of-window views and the flight models had at least moderate level fidelity. However, little has been done since that time to test the efficacy of low cost PCATDs for VFR training.

This thesis provides strong evidence that VFR training is effective in these devices, and establishes the specific conditions under which it is most effective. This finding has substantial implications for the cost of flight training particularly in VFR procedures.

7.4 How does the effectiveness of a PCATD compare to a CAANZ certified FTD when used for training VFR tasks?

The cost of acquiring and maintaining a CAANZ certified FTD is still beyond the financial resources of most small to medium sized flight training schools. In the last decade, technological advances in PC-based software and hardware systems have enabled the development of low cost PCATDs. A number of studies have examined whether these devices provide IFR simulation training that is as accurate and effective as a certified FTD. This study aims to add to the body of limited research into the effectiveness of low cost PCATDs compared to FTDs in relation to VFR skills training.

The Stage 4 PCATD comparative study was characterised by the combination of two unusual elements. A quasi-transfer of training of study that focused on VFR skills performance on a FTD and PCATD coupled with an objective assessment of that flight performance. Both techniques are becoming more popular for the following reasons. The biggest challenge to researching PCATD design or the effectiveness of transfer of training on PCATDs is the difficulty and expense of flight transfer experiments involving real aircraft. The difficulty of using real aircraft can be reduced by using a simulator transfer design, which is defined as a quasi-transfer study. In this case, the transfer of training being measured is to a high fidelity FTD. In support of this methodology, Taylor, Lintern, & Koonce, (1993) found evidence of correspondence between quasi-transfer and transfer. Objective measurement avoids most of the pitfalls of subjective measurement by SMEs. These include observer bias, not enough discrete observations, missing observations due to distractions, and lack of inter-rater or intra- rater reliability.

7.4.1.1 Finding 10

VFR performance can be objectively measured by a PCATD and can be a valuable supplement to flight instructor rating of student performance.

Objective measurement of VFR task performance was used in the Stage 4 PCATD comparative study. The use of flight data recording software in the PCATD and FTD was an unusual technique, and only one other study was found where this technique was adopted (Smith & Caldwell, 2004). A related technique used in-flight data recording equipment installed in the aircraft to record task performance (Roessingh, 2005). Although it is a time consuming process analysing the raw data, the results are usually unambiguous. Normally no perceptual bias can affect the results as long as the statistical analysis is robust and measures are taken to minimise the effect of confounding variables. However, caution should be used when interpreting the statistical results. Overall flight performance is more than the sum of a list of component flight-performance variables. Nevertheless, careful analysis of the data can provide critical insights into training transfer.

In the Stage 4 PCATD comparative study, eight flight tasks were recorded on the FTD, which represented a high fidelity substitute for the real aircraft in a quasi-transfer study. The FTD was used for pre-test and post-test assessment The data was created by the FTDs internal NIFA scoring system which scored a participant's VFR task performance by attaching penalty points to any deviation of altitude, heading, IAS etc. from the installed template. The data was recorded at a high frequency (number of deviations per second), which could not be accomplished using subjective instructor evaluation. The objective VFR performance data indicated that there was no significant difference in VFR task performance between the PCATD and FTD trained groups. This type of data collection and measurement was effective for this comparative study but is markedly different to the usual traditional subjective evaluations conducted by SMEs, who use categorical assessments.

The majority of transfer of training studies uses flight instructors or SMEs to evaluate a pilot trainee's performance in either a simulator or aircraft. This method, based on subjective evaluations is relatively easy to implement, has high face validity and is simple to execute (Johnson & Rantanen, 2005). Most subjective assessments are scored on a five or six point Likert scale. For example, Talleur, Taylor, Emanuel, Rantanen, & Bradshaw (2003) examined the effectiveness of PCATDs for maintaining instrument currency. Flight instructors were required to assess up to 24 variables within instrument flight maneuvers performed by the participants. The flight instructor had to then assess whether the overall performance of each manoeuvre was acceptable. As this example illustrates, subjective assessment is dependent on the skill and experience of the instructor. An inexperienced observer could easily miss subtle changes in performance or be subject to observation bias. The evaluators also require sufficient training to achieve a reasonable level of inter-rater and intra-rater reliability. However, this evaluation method is labour intensive and flight instructors usually have limited discretionary time. In addition, they may not be able to provide enough accurate quantitative data to produce an accurate profile of flight performance of the trainee, due to the limitations of human observation capabilities. For example, subtle behaviours may be overlooked by instructors who tend to focus on behaviours that are more prominent. Finally, the frequency of their observations may not be high enough to capture enough data (Rantanen & Talleur, 2001).

Objective measures of pilot performance based on flight data recordings from either an aircraft or simulator, can alleviate a number of the problems associated with subjective measurement. Objective measures are quantifiable and use identifiable standards by which flight skills performance can be measured. Whatever objective measures are used, they should be repeatable, and criteria based, and for training purposes, are easily accessible for feedback or monitoring. Objective evaluation of flight data is not new and since the 1980s, many different measurement techniques have been trialled.

Vidulich (1991) developed a figure of merit (FOM) of pilot performance from six primary flight variables (control inputs, altitude, airspeed, and heading). The authors created a total FOM (derived from standard deviations of the six variables and the altitude, airspeed and heading means) and specific flight parameter FOMs. For example, an altitude FOM was derived from altitude mean and standard deviation. Rantanen and Talleur (2001) developed a metric calculation defined as mean time to exceed tolerance (MTE). The MTE was calculated from the rate of change between successive data points and the aircraft's position relative to a given tolerance. The MTE was used to calculate a pilot’s performance in tracking the localiser on an instrument landing system (ILS) approach. The MTE was supported as a valid measurement because there was a significant difference between MTE scores of pilots who passed a proficiency check flight, and those who failed a flight instructor evaluation. Virtually all of these objective evaluation studies analysed real-time performance data downloaded from aircraft flight data recorders. Only one study was found that analysed performance data from a simulator.

Smith & Caldwell (2004) assessed and quantified the flight performance of F-117A pilots using a fixed base F-117 simulator. Objective flight- performance data was collected using the Coherent Automated Simulation Test Environment (CoASTE) tool, which had a similar functionality to the NIFA scoring tool used in the Stage 4 PCATD comparative study. Nine flight variables (altitude, airspeed, vertical speed, heading, pitch, roll, slip, localiser, and glideslope) were measured before and after a sleep deprivation cycle to establish if fatigue increased errors in flight performance.

Johnson & Rantanen (2005) completed a literature review of transfer of training studies that used objective assessment. The review indicated that altitude, airspeed, roll, control inputs, heading and pitch were the most frequently measured variables, accounting for over sixty-five percent of all flight parameters measured. These variables would also be the primary ones assessed in the Stage 4 study. Two additional variables, Total Score and Glide Slope would be measured in the Stage 4 evaluation with the last variable Overhead Rejoin Pattern being measured by a SMEs subjective evaluation. Objective assessment was an efficient assessment method for this comparative study, However, it should be noted that despite the long history of objective measurement in flight performance, validation of the technique is still limited, although, some attempts have been made to correlate objective measures with subjective evaluations. In most cases there has been some positive correlation (Wong, Meyer, Timson, Perfect, & White, 2012)

Many PCATDs can use performance measurement software that can be incorporated into the open architecture simulation system (Pardo, 2012). However, many high fidelity simulators do not have this capability. Therefore, low fidelity simulators have significant potential as tools for collecting objective human performance measures based on flight performance variables. Additionally, more research is undertaken on low cost PCATDs because they are more accessible, and can be easily manipulated, whereas high fidelity simulators tend to be used intensively for training, leaving little discretionary time for research purposes. The findings on the greater accuracy of objective measurements of pilot performance in the Stage 4 study provide evidence of the need to supplement flight instructor or SME evaluations of student performance. For example, SME evaluations may not be able to make sufficiently fine discriminations in performance. McDermott (2005a) used flight instructor evaluations but a high number of these scores showed no change (zero score) in pilot proficiency between the pre-test and post-test assessments, which resulted in a non-normal data distribution. The current study used flight-recording analysis of PCATD flight variables instead, which provided a precise measurement of VFR task performance as well as normally distributed data. One exception was the Overhead Rejoin Pattern VFR task, which was too complex for objective analysis and required a categorical assessment by flight instructors. Overall, this study demonstrates early support for the value of objective performance data in both training and research to provide greater accuracy in the measurement of training effect.

7.4.1.2 Finding 11

Quasi transfer of training is an appropriate methodology for comparative studies of transfer of training effectiveness between low cost PCATDs and high fidelity FTDs.

The standard procedure for the evaluation of PCATDs and FTDs tests the transfer of training of IFR/VFR skills to a relevant training aircraft. However, in quasi-transfer methodology students are trained on different configurations of the same device. This methodology was adopted for the comparative study of a low cost PCATD with a high fidelity FTD because of the considerable costs and time associated with using real aircraft. In addition, the use of the FTD for objective testing provided a distinct advantage as the collected flight recording data was very precise and unambiguous compared to subjective evaluations by flight instructors in the aircraft, which was potentially less accurate and subject to bias (Lintern, et al., 1997). Smith (2007) outlined some of the difficulties with subjective evaluation. He stated:

> The reasons for differences in instructor perception of student performance can be systematic or arbitrary, conscious or subconscious, innocuous or malicious; one simply cannot catalogue another’s motives, but one can see the result of the instructors perceptions: difference (p. 1).

Smith found that there were still issues at flight training schools with inter-rater reliability. He suggested that extensive recurrent training for instructors was required and the scoring rubric had to be improved. The comparative study was designed using a quasi-transfer methodology where VFR task performance was tested on a NZ CAA certified FTD as this device represented a high fidelity replica of the real aircraft. A number of similar comparative studies have adopted the quasi transfer methodology with some success (Lintern, et al., 1997; McDermott, 2005a; Proctor, et al., 2007).

A VFR Overhead Rejoin maneuver was chosen for the assessment phase mainly because of the range of different VFR sub-tasks involved in the maneuver, and the spatial orientation and situational awareness required to execute it. The VFR sub-tasks included straight and level, descending, climbing, turning, banking, landing approach, and landing. This maneuver then provided a range of performance measures of VFR sub-tasks. A similar technique was used in Smith & Caldwell (2004) where fifteen advanced VFR tasks were chosen for objective evaluation. These included combined VFR tasks such as climbing and descending turns with heading changes.

The results of the quasi-transfer study support the hypothesis that a PCATD with low to moderate fidelity can be as effective as a high fidelity FTD in improving VFR skills. This hypothesis tends to contradict a number of other training transfer studies that recommended that PCATDs should only be used for IFR skills training (Johnson & Stewart II, 2005; Taylor, et al., 2003; Taylor, et al., 2004). The effectiveness of the SAV2 PCATD for VFR skills training has been supported by statistical analysis but also by the feedback from the participants, which indicated that the majority of participants felt that their VFR task performance skills in completing the Overhead Rejoin manoeuvre improved after training on the FTD or PCATD.

7.4.1.3 Finding 12

The Stage 4 PCATD was equally effective for VFR skills training by ab initio pilots and those with flight experience.

The second comparative study in the Stage 4 PCATD project involved two groups of pilot trainees. One group was predominantly ab initio students and the other group was advanced students with a few undergoing basic instructor training. Although the two groups had significantly different levels of flight experience there was no significant difference in their VFR task performance on the PCATD. Despite experienced pilots exhibiting critical attitudes towards low cost PCATDs they gained as much training benefit from using the PCATD for VFR skills training as ab initio pilots did. This was an important finding as previous research had indicated that pilots with different experience levels prefer different levels of fidelity to perform flight manoeuvres effectively (Alessi, 1988).

This finding extends those of Vaden, Westerlund, Koonce, & Lewandowski (1998) who examined a diverse group of pilot trainees. The sample comprised thirty-nine foreign airline trainees and twenty-four students from the U.S. who were given ten hours of PCATD training between ground school and commencement of flight training. Their results suggest that the PCATD was more effective for those who traditionally required more training to go solo, and had the greatest effect on training performance prior to solo. This study found evidence that despite the inclination of more advanced pilots to perceive high fidelity as being crucial to training, these pilots also made training gains on low fidelity simulators especially at the ab- initio level.

7.5 Conclusions

One of the main goals of this study was to examine the feasibility of developing and using low cost PCATDs for IFR/VFR flight training. A comparative study was undertaken to establish whether a PCATD could be as effective as a FTD in training pilots in VFR tasks. A number of conclusions can be drawn from the findings and these include the practical application of this research and recommendations for future research. Students sometime have to learn many skills within a single flight lesson, which can lead to information overload and a faulty learning process. Low cost PCATDs provide an environment where individual skills can be practiced repeatedly before using them in conjunction with other tasks. This repetitive practice of individual skills is very difficult to accomplish in the aircraft with its myriad of distractions and reinforces the advantages of using PCATDs for more skills training in general aviation flight schools:

1. *A major factor in the successful deployment of the five PCATDs was end user feedback and evaluation during the development phase.*

The acquisition and deployment of high fidelity certified FTDs involves virtually no consultation with the user. Once the high fidelity device has been certified by an aviation authority then the end user's only responsibility is to operate the device according to a set of strict criteria. The context of the simulator matches exactly the role that is simulated in the aircraft. Experimentation is discouraged whereas conformity in procedures training is strongly encouraged. However, the development of low cost PCATDs involves the sharing of knowledge and in many cases exploiting end users expertise. Many challenges in low cost PCATD development such as a lack of suitable software required user evaluation of untried and untested alternatives. On several occasions during the development phase of the Stage 1-5 PCATD projects a serious problem emerged and it was usually end user feedback that helped solve it. For example, the augmentation of flight controls to increase fidelity, the use of multiple flight models, and the frequent updating of the instrument approach database were all solutions to problems initially suggested by end users and implemented in the final PCATD design.

Dahlstrom, Dekker, van Winsen, & Nyce, (2009) argued that when users interact with low fidelity PCATDS they have the opportunity to use innovative improvisation, and tend to be more adaptive, and creative. Using low cost PCATDs in different settings can sometimes create unexpected outcomes or unpredictable effects, which can increase the resilience of pilot trainees. These types of effects rarely occur in high fidelity simulators and could make pilot trainees who train solely on them, unprepared for unusual contingencies in the air. It is clear from the results of the current study that without user collaboration and input, the development of low cost PCATDs could not reach the level of effectiveness and fidelity required for successful transfer.

2. *Matching the correct level of fidelity to the training task is an important consideration when developing low cost PCATDs.*

Alessi (1988) suggested that there is a marginal rate of return on learning and fidelity. At some point in time, additional increases in fidelity would provide diminishing returns in terms of training transfer. In addition, the level of fidelity should be matched to the level of training. For example, the level of fidelity required by a pilot at an advanced stage of training may only confuse an ab-initio pilot due to information overload. In the Stage 1-2, PCATD projects the focus was on IFR task training. Therefore, in both cases, the visual displays were single screen and the FOV was limited to a range of 70°-90°. This level of visual fidelity was adequate for the task requirement and this level of FOV was supported by (Keller, et al., 2003) for IFR task training. The Stage 3-5 PCATDs were developed primarily for VFR task training so a greater emphasis was placed on visual fidelity. However, the current study identified only two training scenarios where high fidelity visual displays were essential; movement from IFR to VFR on final instrument approaches to the runway and identification of landmarks in VFR cross-country navigation exercises. Other VFR tasks such as straight and level flight, and procedural turns could be rehearsed effectively at lower levels of visual fidelity. Reducing visual fidelity when not required can improve the allocation of PCATD resources and improve its overall effectiveness. An advantage of the Stage 1-5 PCATD software was that settings of IFR/VFR task training flights could be pre-configured with the appropriate levels of fidelity.

3. *The effectiveness of transfer of training in PCATDs is independent of cost*.

All of the Stage 1-5 PCATD projects were constrained by limited budgets. In Stage 1 and Stage 3, the project requirement was even more difficult to achieve within the financial allocation because multiple PCATDs had to be developed. During the development of the five PCATD projects the average cost of a high fidelity certified FTD ranged from $500,000 -$100, 000. The Stage 1-5 PCATDs were all produced for a fraction of this cost ($5000 - $80,000). In addition, the Stage 1-5 PCATD project achievements included development of fixed wing and rotary wing simulators, civil aviation authority certification for two devices, a comparative study, and formal acceptance of four of the devices into the training curriculum. The rapid technological development of full flight simulator fidelity, capability, and realism coupled with increased complexity, and spiraling costs, has continued to raise serious questions from the research community.

For example, in 2007 military training organisations operated 1,470 high fidelity simulators worldwide, with either a motion platform and /or a visual display system. The most expensive devices were Full Mission Simulators (FMS), which use high-fidelity, visual display systems overlaid onto a 360 degree dome (Strachan, 2010). Unfortunately, this emphasis on technological development has meant that training needs analysis has been neglected. In comparison, the successful deployment of the five PCATDs in the current study has provided further evidence of the task training effectiveness of low cost PCATDs. However, the development and successful deployment of these PCATDs was only achieved by comprehensive user feedback, detailed task analysis and IFR/VFR task evaluation. In addition, extensive collaboration with instructional staff was required to incorporate these devices into the training curriculum.

4. *The primary focus of legacy simulator training has been IFR task transfer but there has been an increased requirement for low cost PCATDs that can be used for effective VFR task training.*

Currently, civil aviation authority certification approves FTDs and PCATDs for specific IFR tasks such as instrument ground training, rating requirements, instrument currency, and GPS proficiency. A set number of IFR task hours can be completed in the approved device instead of the more expensive aircraft and recorded as flight time in a student pilots log (CAANZ SOA, 2011). However, there is no specific PCATD certification for VFR task training. The Stage 3-5 PCATDS were used for a significant amount of VFR skills training but these PCATD hours could only be logged in the flight simulator column in the students' logbook. They are not classified as flight hours and cannot be logged in the flight time (total time) column. However, two critical issues have emerged in the aviation industry that directly relate to a need for a re-emphasis on VFR skills training at the ab-initio level. The airline industry has had to implement upset recovery training programmes because from 1998-2007, 25% of all transport aircraft crashes were attributed to loss of flight control (Leland, et al., 2009). Also, with the worldwide introduction of glass cockpits in general aviation aircraft, the Aircraft Owners And Pilots Association (AOPA) Air Safety Foundation noted that lack of basic piloting skills such as aircraft landings were significant factors in accidents with technically advanced aircraft (Greenway, 2010). SMEs have suggested that student pilots' may need to complete additional hours of VFR skills aiming at the ab initio level and a portion of this training could be completed in PCATDs

The current study provides additional evidence of the effectiveness of low cost PCATDs in improving pilot trainees VFR task skills, and proposes that some VFR training time completed in a certified PCATD should be credited towards a PPL or CPL.

5. *PCATDs used for ground training in a flight-training organisation are much less effective unless they are formally implemented into the flight-training curriculum.*

A survey of NZ flight-training organisations conducted as part of this study indicated that there was widespread use of PCATDs but in an informal and ad hoc manner. In most cases, these devices had been developed by students and usually consisted of a PC or laptop computer, flight simulation software, and some basic flight controls. Although they represented some training value in terms of self-directed learning (Dunlap & Tarr, 1999), they were not formally adopted into the flight training programme and had little official support.

Senior flight instructors expressed concern that these devices and their unsupervised use could cause negative transfer. However, as part of a formal training programme most components of the training curriculum can be learnt to a criterion performance level in a PCATD before demonstrating competency in the aircraft. Implementing PCATDs into a flight-training curriculum has a number of additional training benefits such as remedial training for pilots who are struggling to keep up with exercises in the air. PCATDs also provide the incentive to structure a more integrated ground and flight-training programme. Current flight training programmes have two components, ground school and flight school. Ground school is where trainee pilots are taught relevant knowledge, such as meteorology, systems, aerodynamics, airmanship, etc. The flight-training programme teaches flight skills, takeoffs, landings, turns, circuits etc. An integrated flight-training programme could improve its effectiveness by increasing the utilisation of PCATDs, which can provide feedback and evaluation, repetition learning, and review of those flight tasks where the pilot trainee requires assistance. In this study, four out of five PCATD projects were incorporated into their respective training programmes and this meant the PCATDs were used more effectively within a structured curriculum. The formal adoption of PCATDs into the curriculum also meant that the devices gained an increased level of acceptance as legitimate training aids by instructors and students.

6. *Due to advances in technology and changes in the training curriculum, common distinctions between PCATDs, FTDs, and FFSs are beginning to blur and become less relevant.*

In the past PCATDs were identified as training devices that could be used for self-directed learning, remedial training and general IFR or VFR training but were definitely not certified by a civil aviation authority for conducting practical tests, training for instrument ratings or recency of experience instrument training (CASA, 2002). However, this began to change when the FAA (one of the first authorities to do so) promulgated new rules that provided greater flexibility in the use of these devices, in training for certificates, ratings, and to maintain instrument currency (FAA, 2008). Other civil aviation authorities followed the FAA's direction by promulgating similar rules (CAANZ, 2011a). The level of fidelity was another common method of categorising the different devices.

This worked well when classifying high fidelity full flight simulators but was becoming less clear for FTDs and PCATDs. This study demonstrated, that PCATDs can be equipped with motion platforms, large multi-screen displays, and replica cockpits, and in some cases have higher levels of fidelity than early model FTDs. The development of low cost PC-based technologies has increased rapidly and this has advanced the training capability of PCATDs significantly. Even MSFS is now installed on some FTDs whereas in the past only proprietary simulation software would have been used (Redbird, 2010). The confusion surrounding the classification of these devices was addressed by the International Working Group (IWG). This group of SMEs was tasked by ICAO with the re- classification of all synthetic flight-training devices and they performed a detailed analysis of training tasks and then assigned fidelity levels to 12 distinct simulator features. This new classification was much simpler and identified seven new device types - Levels I to VII – which span the complete range of training device from desktop trainer to full-flight simulator (Cook, 2006).

7.6 Practical Applications & Future Research

This study has outlined the development of five PCATDs designed for IFR/VFR skills training. It includes their evaluation, integration with the flight-training curriculum, and in two cases NZ CAA certification. Additional project extensions examined the use of

PCATDs for military UAV operator flight- training, and training Search & Rescue Aircrew in GPS Search pattern tracking. Two post-graduate students have completed studies on the Diamond DA 40 PCATD. One student completed a study on automation complacency (Weng, 2010) and another completed a comparative study on the training effectiveness of conventional cockpits versus glass cockpits (Johnson, 2011). A number of research possibilities have emerged with the development of these PCATDs and they follow the action research principle of identifying a problem and then investigating possible solutions:

1. Around the world, controlled airspace has become more congested and boundaries more complicated. There has been a steady increase in airspace violations committed in the last few years. The majority of these incursions were committed by student pilots on navigation exercises or transiting to or from designated training areas (Anstiss, 2012). The use of opaque airspace boundaries generated and overlaid as a 3D computer graphic onto the synthetic terrain in a PCATD could be an effective training tool. This would enable student pilots to practice cross-country navigation or transitions in the PCATD in real time, gain more familiarity with airspace boundaries, and correctly match them with local landmarks.

2. Flying aircraft places heavy demands on a pilot's physical condition, psychomotor skills, and cognitive-perceptual abilities. The identification of potential candidates that are most likely to complete their flight training successfully has been a difficult predictive exercise (Carretta & Malcolm, 1994). It can involve a battery of psychometric and personality tests as well as possible trial flight in an aircraft. This procedure can be time consuming and expensive. The Diamond Da 40 PCATD used a pilot selection tool instead of aircraft trial flights for a period of two years. A flight instructor assessed potential candidates on a number of VFR maneuvers in the PCATD as the practical psychomotor component of pilot selection. A longitudinal study is required to compare performance in the PCATD with performance on the flight-training course to assess the predictive powers of the PCATD practical test.

3. The equipment and system tasks are becoming increasingly complex in modern Technically Advanced Aircraft (TAA), and the requirement for integration of cognitive and physical skills has also increased (FAA, 2012b). The FAA/Industry Training Standards (FITS) Scenario Based Private/Instrument Generic Syllabus for Technically Advanced Aircraft recommends that Aviation Training Devices (ATD) represent an opportunity to plan and control scenarios that are more inherently safer to practice in an ATD than the aircraft (FAA, 2006). Scenario Builder is a MSFS compatible software package designed with the FAA/Industry Training Standards (FITS) in mind, and is a FITS-accepted product. It can be used to create simulation scenarios that focus on Scenario-Based Training (SBT), Single-Pilot Resource Management (SRM), and Learner-Centered Grading (LCG). More research is required to see what type of simulation scenarios developed for the Diamond DA 40 PCATD are the most effective for scenario-based training.

4. The Virtual Air Traffic Simulation Network (VATSIM) is a non-profit organisation, which has over 250,000 registered virtual pilots and air traffic controllers who use PC-based flight simulators in a real-time multiuser global aviation system. VATSIM provides ATC services for over 20,000 virtual airports (Vatsim, 2011). Most PCATDs are internet ready and could be easily connected to VATSIM for training purposes. Little research has been undertaken on how flight training schools could incorporate this vast online resource into their training curriculum.

5. Relatively low cost flight controls with force feedback and high levels of fidelity have been a major technological barrier. The recent development of COTS hydraulic joysticks can provide force feedback at an affordable price and these devices have the potential to improve the transfer of training of psychomotor skills (Paccus, 2012). Collaboration with the manufacturing company has already commenced to evaluate the effectiveness of these new flight controls when used in a CAANZ certified PCATD.

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Appendices

APPENDIX A: Microsoft Flight Simulator Software Architecture

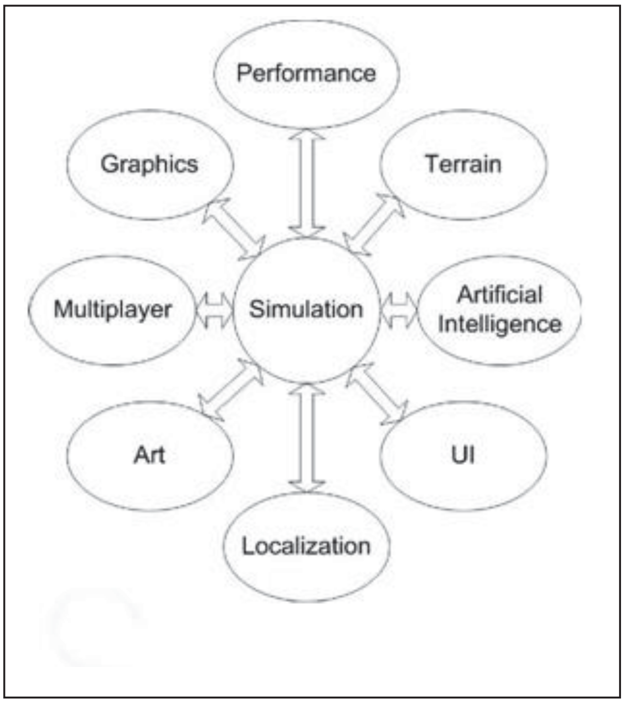


Figure A1. Microsoft Flight Simulator Conceptual Design

Source: (Zyskowski, 2010, Fig. 3)

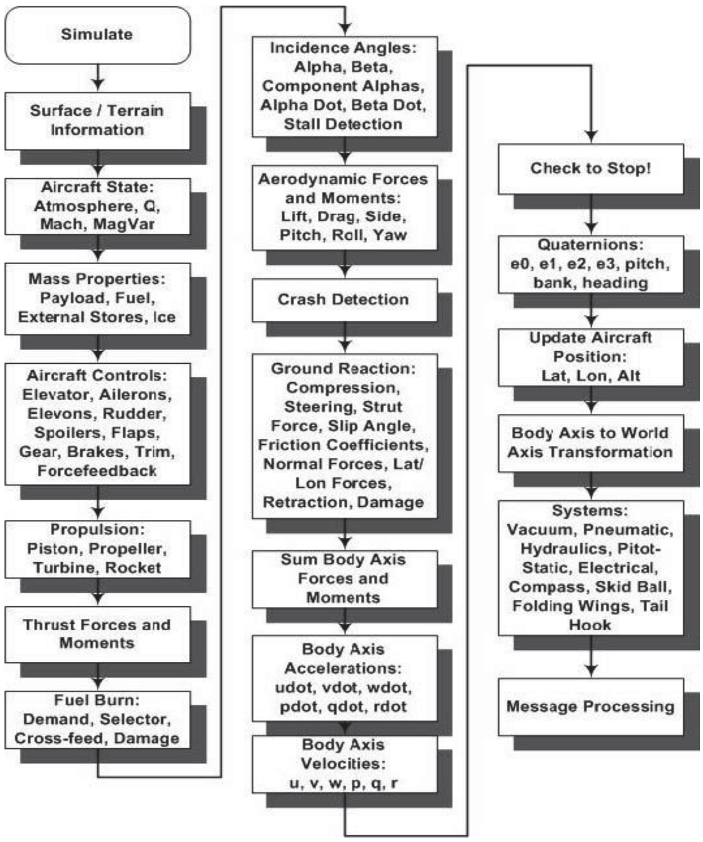


Figure A2. Microsoft Flight Simulator Software Components

Source: (Zyskowski, 2010, Fig. 5)

APPENDIX B: Microsoft Flight Simulator Versions

Figure B1. Microsoft Flight Simulator Versions

Source: (WikiMedia Foundation, 2010)- History of Microsoft Flight Simulator: Retrieved from http://en.wikipedia.org/wiki/History_of_Microsoft_Flight_Simulator & (Grupping, 2010) - The History of Microsoft Flight Simulator. Retrieved from http://fshistory.simflight.com/fsh/timeline.htm & (Havlik, 2010)- Czech Flight Simulator History Website-Timeline. Retrieved from http://www.volny.cz /havlikjosef/timeline english.ht

APPENDIX C: NZ Flight Training Organisation Survey.

Date:

Dear Participant

My name is Savem Reweti. The purpose of this letter is to invite you to complete a survey on NZ Flight Training Organisations. I am conducting as part of my Doctoral studies. The title of my thesis is

“PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures: Development, Validation and Effectiveness”

There is no risk to your pilot training or your current pilot qualification and all data collected will be anonymous and confidential. Your pilot experience, and responses on the Questionnaire, will be coded with a random reference number to protect your confidentiality.

Survey Form

Name of Organisation,____

Address ____

Phone Number_________________

Type of Aircraft in your FTO_______________________________________

Date of Survey ________________

Time of Survey________________

Respondent Reference Number ________

1. How many aviation students would you train in a year? ____________
2. Do you currently utilise a certified FTD in your training organisation? Yes/No (If so what type, cost, when purchased etc.)
3. Do you currently utilise a Desktop PC-based Aviation Training Device in your training organisation? Yes/No (If so what type, cost, when purchased etc.)
4. Do you currently utilise a Desktop PC-based Part Task Trainer in your training organisation? Yes/No (If so what type, cost, when purchased etc.)

5. Do you perceive any benefits in the utilisation of FTDs, PCATDs or Part Task Trainers in your training organisation? Yes/No

6. Do you intend to purchase or lease any of these devices in the near future? Yes/No

7. What are the major factors precluding your use of these devices in your training organisation?

8. If your training organisation could have access to a certified FTD at a reasonable cost and was located less than 100 km away would your training organisation be interested in such a device? Yes/No

9. If a customised PCATD could be produced for your training organisation at a cost of less than $10,000 would your training organisation be interested in such a device? Yes/No

10. Do your students utilise PC-based software such as Microsoft Flight Simulator 2004 or X-planes on an informal basis to assist in their training? Yes/No

11. Please make any other relevant comments you feel may assist this survey

APPENDIX D: NZ Aviation Organisation Database

Ace Aviation	Flight Training Manawatu	Nelson Aero Club Inc.
Accelerated Flight Testing Ltd	Flightline Aviation Ltd	Nelson Aviation College
Actionflite Queenstown	FoxPine Airpark Ltd	Nelson Helicopters
Advanced Flight - Helicopter Services	Garden City Helicopters Ltd	Nelson Paragliding School
Air Adventure - Oshkosh	Gavin Wills Mountain Soaring	New Plymouth Aero Club
Air Charter Manawatu Ltd	Geraldine Flying Group	New Zealand Helicopter Centre Ltd
Air Discovery Limited	Gisborne Flying School	New Zealand Sport & Vintage Aviation Society Inc.
Air Gisborne Ltd	Gliding Club Wanganui-Manawatu	North Otago Aero Club Inc.
Air Hawke's Bay Ltd	Gliding Hawkes Bay	North Shore Aero Club
Air Milford	Gliding New Zealand	North Shore Helicopter Training Ltd
Air New Plymouth Flight Training	Gliding Wairarapa	Northern Wairoa Aero Club (Inc.)
Airline Flying Club Inc.	Gliding Wellington	Northland Districts Aero Club Inc.
Alpine Air Services	Hawera Aero Club	Otago Aero Club Inc.
Ardmore Flying School Ltd	Hawera Aero Club Inc.	Otamatea Aero Club (Ruawai) Inc.
Ashburton Aero Club refer Mid Canterbury Aero Club	Hawkes Bay East Coast Aero Club	Pacific Simulators Ltd
Associated Aviation	Helicopter Services BOP Ltd / Heli Harvest Ltd	Piako Gliding Club - Matamata
Auckland Aero Club Inc.	Heli-Flight Masterton	ProFlight
Auckland Flight Training	Heli-flight Wairarapa Ltd.	Quantum Aviation
Auckland Gliding Club	Heli-Guides (Heli Ski Queenstown)	RNZAF Base Ohakea, PTS
Back Country Helicopters	Helipro Helicopters Rotorua	Rodney Aero Club
Bay Flight International	HeliPro Helicopters Wellington	Rotaworx
Bay Of Islands Aero Club	HeliPro Helicopters Palmerston North	Rotorua Aero Club
Bulls Flying Doctor Service Ltd	Helipro Helicopters Paraparaumu	Shoreline Helicopters Ltd

Canterbury Aero Club Inc.	International Aviation Academy of New Zealand	Sky Signz Ltd Aerial Advertising
Canterbury Aviation Ltd	Island Air Charters	South Canterbury Aero Club
Capital Jet Services Ltd	Izard Pacific Aviation	Southern Air Services Ltd
Catalina Club of New Zealand	Jury Hill Gliding Club (Inc.)	Southern Soaring
Central Otago Flying Club	Kaikoura Aero Club	Southern Wings
CHB Aero Club	Kaitaia Aero Club Inc.	Southland Aero Club
Christchurch Flying School	Kapiti Aero Club	Stratford Aero Club
Christchurch Helicopters	Mainland Air Services	Taranaki Gliding Club
Christchurch Parachute School - Skydiving in Christchurch	Manawatu Districts Aeroclub	Tauranga Aero Club Inc.
Christian Aviation	Marlborough Aeroclub	Waikato Aero Club
Claremont Ferrand: Aviation & Tourism Services	Massey University Aviation (Milson Flight Centre)	Wairarapa & Ruahine Aero Club
CTC Aviation Training (NZ) Ltd	Matamata Aero Club	Wakatipu Aero Club
Eagle Flight Training Limited	Mitchell-Anyon Developments (MAD)	Wanganui Aero Club
Euro Flight International Limited	Motueka Recreational Flight Training Ltd	Wellington Aero Club
Fiordland Aero Club Inc.	Mount Cook Skiplanes	Wellington Flight Centre
Flight Experience	Mt Anglem Helicopters	Wings Flight Training Academy
Flight Park Queenstown Ltd	Mt Hutt Helicopters	Wyndon Aviation Ltd

APPENDIX E: PCATD Evaluation Template

Date:

Dear Student

My name is Savem Reweti. I was involved in the development of three PC-based Aviation training Devices (PCATDs) which are used for PTS IFR/VFR training. .I only had a very limited budget to build the devices but with a great deal of support from students and flight instructors at PTS it is pleasing to see that the devices still have some training benefit. The purpose of this letter is to invite you to complete a survey I am conducting as part of my Doctoral studies. The title of my thesis is

"PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures: Development, Validation and Effectiveness"

There is no risk to your pilot training or your current pilot qualification and all data collected will be anonymous and confidential. Your pilot experience, and responses on the Questionnaire, will be coded with a random reference number to protect your confidentiality.

Questionnaire

(PC-Based Aviation Training Device Evaluation)

Please answer all questions

Participant Number ___________

Question No.	Question Detail	Response
1	What is your age ?	________
2	What is your total accumulated Flight Time in the Airtrainer?	_______Hrs
3	What is your total Instrument Training Flight Time in the Aircraft?	_______Hrs
4.	Is this the first time you have practiced instrument skills training in a PCATD?	Yes/No (please circle)
5.	How many hours training have you completed on the PTS PCATDs?	_______Hrs

6. What types of instrument approaches have you practiced on the PTS PCATDs? VOR/VOR-DME /ILS/NDB/VORTAC (please circle)

7. Practicing this particular IFR/VFR flight procedure or manoeuver in the PCATD can improve proficiency in the aircraft (Tick appropriate choice)

Manoeuvre	Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
Instrument Scan	O	O	O	O	O	O
Airspeed Control	O	O	O	O	O	O
Altitude Control	O	O	O	O	O	O
Navaid Tracking	O	O	O	O	O	O
Procedural Turns	O	O	O	O	O	O
Holding Patterns	O	O	O	O	O	O
Intercept Localizer	O	O	O	O	O	O
Intercept Glide Slope	O	O	O	O	O	O
Missed Approach	O	O	O	O	O	O
SID rehearsal	O	O	O	O	O	O
STAR Rehearsal	O	O	O	O	O	O

8. The physical fidelity of the flight controls is at a high enough level in terms of accuracy and feedback response to conduct effective IFR/VFR training.

Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
O	O	O	O	O	O

9. The resolution of the NZ terrain depicted in the PCATD is accurate enough to conduct effective IFR/VFR training.

Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
O	O	O	O	O	O

10. The flight model characteristics of the Airtrainer CT4E developed for the RNZAF PCATD accurately match the real aircraft.

Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
O	O	O	O	O	O

11. The instrument panel depicted in the PCATD was realistic enough to conduct effective IFR/VFR training.

Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
O	O	O	O	O	O

12. The PCATD out-of-cockpit-views provide FOV fidelity at a high enough level, to conduct effective IFR/VFR training.

Strongly Disagree	Moderately Disagree	Neutral	Moderately Agree	Strongly Agree	Unable to Rate
O	O	O	O	O	O

13.. Please provide any other feedback on the PCATD (problems improvements , limitations etc.)

<u>1.Participant Instructions for Task Evaluations</u>

In the first phase you can practice a procedure or training task (e.g., Missed Approach) either as a component of a complete training procedure (e.g., full instrument approach) or as a completely separate, individual exercise. Each procedure should take no more than 15-30 minutes to complete but you can repeat the procedure until you feel confident that you have mastered it. Please evaluate all procedural tasks listed on the evaluation sheet, in the PCATD using an Airtrainer CT4E flight model. If you are not sufficiently qualified to evaluate the manoeuvre (e.g., STAR), then tick the ‘Unable to Rate’ circle.

<u>2.Participant Instructions for Heuristic Evaluation</u>

Please complete the heuristic evaluation individually. Do not consult with your colleagues. Thank you for your participation

APPENDIX F: TRACMAP Link To Microsoft Flight Simulator

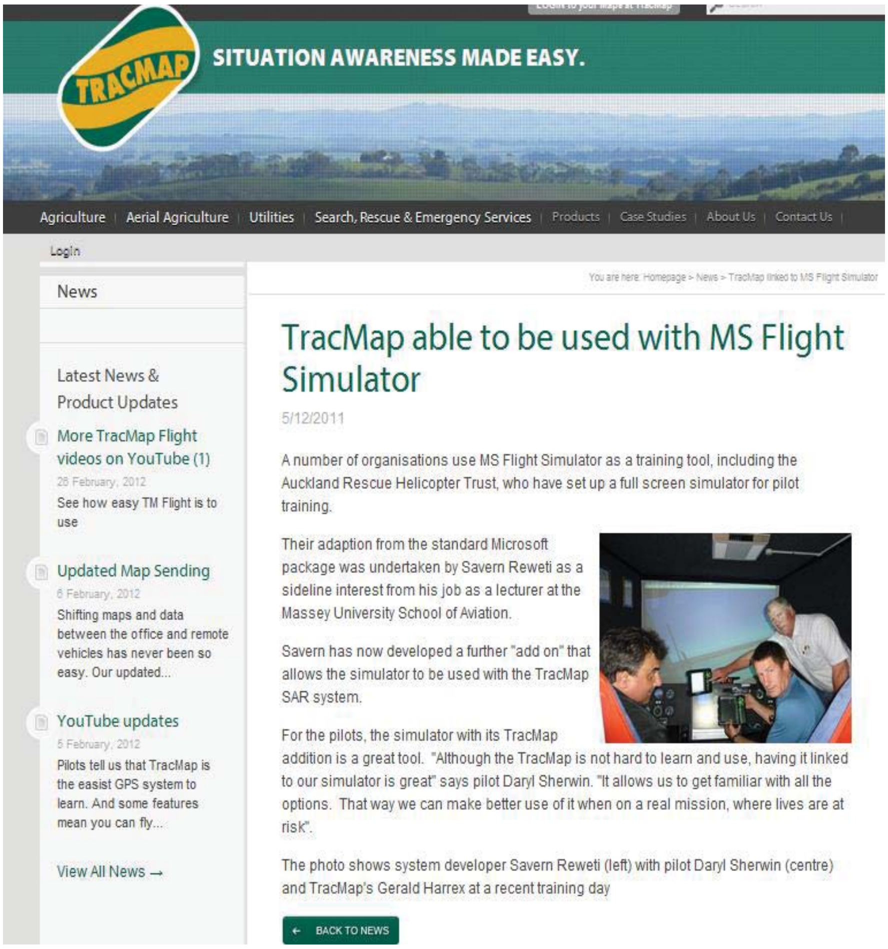


Figure F1. TracMap Linked to MSFS

Source: (TracMap GPS, 2011) TracMap able to be used with MS Flight Simulator. Retrieved from http://www.tracmap.com/news/tracmap-linked-to-ms-flight-simulator

APPENDIX G: ARHT Synthetic Training Device Approval

CIVIL AVIATION AUTHORITY OF NEW ZEALAND

Synthetic Training Device

This is to certify that

Auckland Regional Rescue Helicopter Trust

Trading as Auckland Rescue Helicopter Trust

is permitted to use the following Flight and Navigation Procedure Trainer:

ARHT Sim 09 S/N 001

This certificate is not transferable, and shall come into force on the 15th day of September 2010 and remain in force until the 15th day of September 2012 unless otherwise suspended or revoked.

Granted this 15th day of September 2010

for Director of Civil Aviation

This certificate is granted pursuant to Civil Aviation Rule Part 61.33

No. STD34326

Figure G1. ARHT PCATD CAANZ Certification

CIVIL AVIATION AUTHORITY OF NEW ZEALAND

Synthetic Training Device Purposes And Conditions

20 SEP 2010

Auckland Regional Rescue Helicopter Trust

This Specification forms part of Certificate No. STD34326 granted pursuant to CAR Part 61.33.

1. Address For Service

Auckland Regional Rescue Helicopter Trust
3 Solent Street
Mechanics Bay
AUCKLAND
1001

2. Trading Names

Trading as Auckland Rescue Helicopter Trust

3. Permitted to use the following STD:

ARHT Sim 09 S/N 001

4. Approved Purposes:

Purposes:

(a) Two hours instrument ground time towards the issue of a Private Pilot Licence - Helicopter (AC61-3, Appendix I);

(b) Five hours instrument ground time towards the experience requirement for night cross country by a Commercial Pilot Licence - Helicopter (AC61-5, Appendix I);

(c) Five hours instrument ground time towards the issue of a Category C or B Flight Instructor Rating - Helicopter (AC61-18, Appendix I);

(d) Twenty hours instrument ground time towards the issue of an Instrument Rating - Helicopter (AC61-17);

(e) Two hours of instrument ground time towards the currency requirements of an Instrument Rating - Helicopter [CAR Part 61.807 (a)(2)(i)];

(f) One GNSS, NDB, VOR, LLZ or ILS approach procedure toward the currency requirements of an Instrument Rating - Helicopter [CAR Part 61.807(a)(2)(ii)];

(g) One GNSS, NDB, VOR, LLZ (non-precision) or ILS (precision) approach procedure toward approach currency requirements of an Instrument Rating - Helicopter in any one 3 month period [CAR Part 61.807(a)(4)];

(h) Conduct of the cross-country portion and any one approach of every alternate Instrument Rating Annual Competency Demonstration - Helicopter [required by CAR Part 61.801(a)(6)].

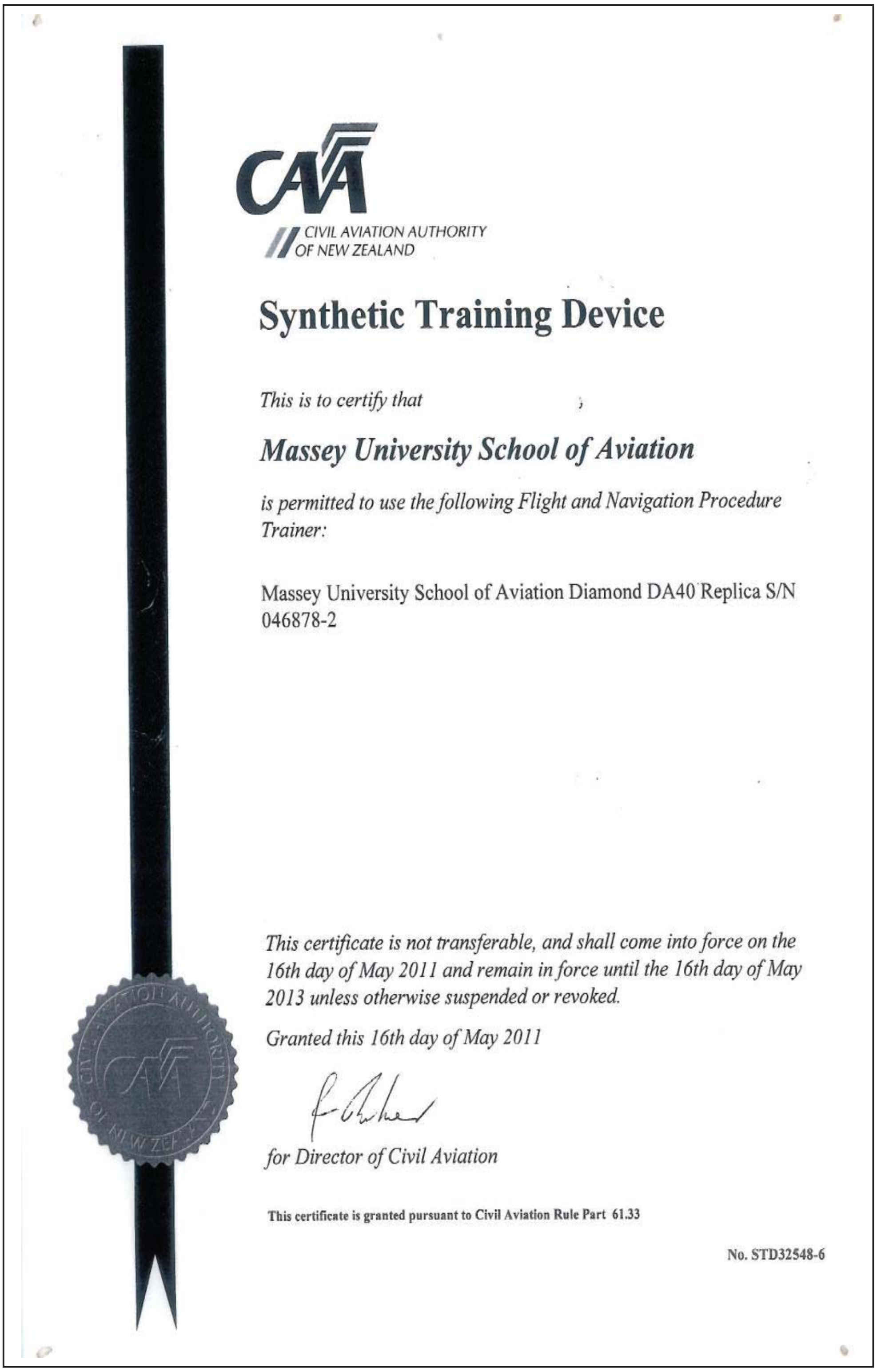
STD34326 Auckland Regional Rescue Helicopter Trust

Accepted By: .... Dated 17 September 2010

Page 1 of 2

Figure G2. ARHT PCATD CAANZ Approved Purposes

APPENDIX H: Massey University SOA SFTD Approval



CAA
CIVIL AVIATION AUTHORITY
OF NEW ZEALAND

Synthetic Training Device

This is to certify that

Massey University School of Aviation

is permitted to use the following Flight and Navigation Procedure Trainer:

Massey University School of Aviation Diamond DA40 Replica S/N 046878-2

This certificate is not transferable, and shall come into force on the 16th day of May 2011 and remain in force until the 16th day of May 2013 unless otherwise suspended or revoked.

Granted this 16th day of May 2011

for Director of Civil Aviation

This certificate is granted pursuant to Civil Aviation Rule Part 61.33

No. STD32548-6

Figure H1. Massey SOA PCATD CAANZ Certification

Synthetic Training Device - Purposes And Conditions - Massey University School of Aviation

3. Permitted to use the following STD:

Massey University School of Aviation Diamond DA40 Replica S/N 046878-2

4. Approved Purposes:

Purposes:

(a) Two hours instrument ground time towards the issue of a Private Pilot Licence - Aeroplane (AC61-3, Appendix I);

(b) Five hours instrument ground time towards the issue of a Commercial Pilot Licence - Aeroplane (AC61-5, Appendix I);

(c) Five hours instrument ground time towards the issue of a Category C or B Flight Instructor Rating - Aeroplane (AC61-18, Appendix I);

(d) Ten hours instrument ground time towards the issue of an Instrument Rating - Aeroplane (AC61-17);

(e) Two hours of instrument ground time towards the currency requirements of an Instrument Rating - Aeroplane [CAR Part 61.807 (a)(2)(i)];

(f) One RNAV(GNSS), NDB, VOR, LLZ or ILS approach procedure toward the currency requirements of an Instrument Rating - Aeroplane [CAR Part 61.807(a)(2)(ii)];

(g) One RNAV(GNSS), NDB, VOR, LLZ (non-precision) or ILS (precision) approach procedure toward approach currency requirements of an Instrument Rating - Aeroplane in any one 3 month period [CAR Part 61.807(a)(4)];

(h) Demonstration of Garmin 1000 GNSS as a subsequent type and model (AC61-17, Appendix II).

5. Approved Conditions:

This approval is subject to the following conditions:

1. Each instructor shall be specifically approved by Massey University School of Aviation for the purpose of instructing on the Massey University School of Aviation Diamond DA40 Replica in accordance with the company's Synthetic Flight Trainer Manual (SFTM);
2. Each instructor shall hold a current flight instructor rating in respect of approvals (a), (b) and (c) and a current instructor rating and current instrument rating aeroplane in respect of approvals (d), (e), (f) and (g), and current flight examiner rating privileges in respect of approval (h): Neither instructor nor examiner need maintain a current medical certificate for training or examining in the simulator;
3. The device shall be maintained to a level where it can meet the specific performance tasks required of it and in accordance with the company's SFTM;
4. Instruction details and times shall be entered in the candidate's logbook as instrument ground time, and each entry signed by the approved instructor who gave the instruction;
5. This certificate shall be displayed in the vicinity of the trainer for public viewing.

Unless either surrendered by the holder or suspended or cancelled by notice in writing from the Director this cert

STD32548 Massey University School of Aviation

Accepted By: .... Dated 17 May 2011

Page 2 of 2

Figure H2. Massey SOA PCATD CAANZ Approved Purposes

APPENDIX I. CAANZ Approved Synthetic Trainer Standards

Introduction

This form details the standards required for approved synthetic trainers. These standards are set out as a checklist, which can be used as the ‘accreditation test guide’. The list is in two parts: *Part 1 - Physical Characteristics* and *Part 2 - Operating Characteristics*. Each part is further divided into sections under logical headings. The form incorporates the requirements for all categories of synthetic trainer. The particular requirements for category B synthetic trainers are annotated with symbol (B). Category C synthetic trainers must meet all category B requirements, plus those annotated with the symbol (C).

Inspectors should be aware that the standards for switches and controls, other than flight controls, set out in Part 1 - Physical Characteristics is deliberately non-prescriptive. The word ‘conventional’, when applied to these items, should be taken in its broadest sense. The switches or avionics controls do not need to be ‘realistic’, they only need to be reasonably ‘user friendly’ and perform the functions required, thereby providing realistic cockpit management tasks.

Note: A copy of this document, and those subsequently used in recurrent fidelity checks, must be retained permanently with the trainer.

Synthetic Trainer Details

Operator: .... ARN: ....
Make: ....
Model: .... Serial Number: ....
Software Name: .... Version Number: ....
Hardware Specification ………………..:...

Synthetic Trainer Operations Manual

STOM satisfactory in all respects …………………………………………………..….Yes ❑ No ❑

Inspector’s Certification

This synthetic trainer *satisfies/does not satisfy FSD 2 standards.
*(*delete as required)*
Inspector’s Name: ....
Signature: ....

Date: ....

PART 1 - PHYSICAL CHARACTERISTICS

1.1 General

Located in a dedicated area free from obtrusive light, noise or vibration.................. Yes ❑ No ❑

Size and shape of the enclosure compatible with the cockpit environment .... Yes ❑ No ❑

Computer hardware capacity meets the minimum specification required to operate the software (where appropriate).. Yes ❑ No ❑

A pilot/s instructor intercom is provided.. Yes ❑ No ❑

1.2 Pilot Station/s

Checklists are readily available for normal, simulated emergency and REAL emergency procedures .... Yes ❑ No ❑

Size, general appearance and layout resemble a conventional single or multi-engine aircraft, as appropriate .... Yes ❑ No ❑

Panel, instrumentation, switches, controls and their layout resemble that of a conventional aircraft .... Yes ❑ No ❑

(C) Hardware and sound system standards applicable to flight simulators set out in subsections 11.1 and 11.4 of FSD 1 .... Yes ❑ No ❑

The representation and functioning of any electronic or cathode ray tube displays are realistic, stable, free from distortion or other distracting phenomena........................ Yes ❑ No ❑

All cockpit instruments, indicators, switches and controls can be viewed simultaneously .... Yes ❑ No ❑

Instrument and cockpit lighting are adequate... Yes ❑ No ❑

Pilots' normal field of view excludes all but the cockpit environment and is free from distractions.. Yes ❑ No ❑

(B) A conventional pilot/s radio transmit facility is available for simulated radio communication .... Yes ❑ No ❑

Aeroplane synthetic trainer controls and their indicators include:

- Control column or control wheel.. Yes ❑ No ❑

 Rudder pedals .... Yes ❑ No ❑

 Wing flap selector and position indicator (where appropriate)............................ Yes ❑ No ❑

 Undercarriage selector and position indicating system (where appropriate) .... Yes ❑ No ❑

 Throttle/power lever/s.. Yes ❑ No ❑

 Propeller control/s (where appropriate).. Yes ❑ No ❑

 Elevator trim and position indicator .... Yes ❑ No ❑

 Rudder trim and position indicator in multi-engine synthetic trainers................. Yes ❑ No ❑

(B) A stall warning device .... Yes ❑ No ❑

(B) Mixture control (where applicable) .... Yes ❑ No ❑

(B) Carburettor heat control (where applicable)... Yes ❑ No ❑

 Fuel tank selector (where applicable).. Yes ❑ No ❑

 Fuel quantity indicator/s .... Yes ❑ No ❑

Helicopter synthetic trainer controls and their indicators include:…………………Yes ❑ No ❑

 Cyclic pitch control stick.. Yes ❑ No ❑

 Collective pitch control lever .... Yes ❑ No ❑

 Tail rotor control pedals .... Yes ❑ No ❑

 Throttle (where applicable) .... Yes ❑ No ❑

(B) Throttle/speed select lever/s (where applicable) .... Yes ❑ No ❑

(B) Mixture control (where applicable) .... Yes ❑ No ❑

 Cyclic trim switch... Yes ❑ No ❑

 Control friction .... Yes ❑ No ❑

 Fuel quantity indicator... Yes ❑ No ❑

1.3 Instructor Station

Checklists are readily available for normal and REAL emergency procedures....... Yes ❑ No ❑

Instructor's console and controls are outside the pilots' field of view .... Yes ❑ No ❑

The instructor's location is suitable to maintain surveillance of the pilot, the trainer's instruments and switches and the flight path display .... Yes ❑ No ❑

The instructor can impose the effect of omni-directional wind on the trainer's flight path, with selectable increments of at least 30° in direction and 5 knots in speed up to at least 30 knots .... Yes ❑ No ❑

A method of creating at least three levels of in-flight turbulence is provided .... Yes ❑ No ❑

A flight path display is provided, in azimuth and elevation, relative to the navigation aid/s.. Yes ❑ No ❑

The flight path display provides a record of the simulated flight path for student debrief.. Yes ❑ No ❑

(B) The flight path display plots in relation to a representative current Australian radio navigation chart .... Yes ❑ No ❑

(B) A system is provided for the instructor to distinguish between pilot/s intercom communication and simulated radio transmissions .... Yes ❑ No ❑

1.4 Instrument Systems

Instrument presentation, markings and layout are 'conventional'…………………. Yes ❑ No ❑

Basic operational instruments available include:

Instrument Minimum Range

- ASI Appropriate, marked in knots .... Yes ❑ No ❑
- Altimeter 0 - 9 999 feet adjustable sub-scale in HPA .... Yes ❑ No ❑
- Compass 360°.. Yes ❑ No ❑

 Clock Hours, minutes and seconds.. Yes ❑ No ❑

 VSI, for helicopters, IVSI ±1200 fpm... Yes ❑ No ❑

 AI Pitch +20,° -10°
Roll ±60°

for helicopters, a 5-inch display.. Yes ❑ No ❑

(B) DG 360° adjustable heading bug.. Yes ❑ No ❑

 T & S/Turn Coordinator

Slip only where extra AI is fitted.

Slip only for helicopters ±Rate one .... Yes ❑ No ❑

 VSI ±2000 fpm.. Yes ❑ No ❑

The following engine instruments with representative markings, including limitations, are fitted:

 Tachometer/propeller/rotor speed .... Yes ❑ No ❑

 Manifold pressure/torque(where applicable).. Yes ❑ No ❑

 Oil pressure... Yes ❑ No ❑

1.5 Radio Navigation Systems

Instrument presentation, markings, layout, controls and frequency selection are

'conventional'.. Yes ❑ No ❑

ADF or VOR is available for pilot navigation. .... Yes ❑ No ❑

(B) Navigation aid frequency bands are conventional and tuneable by the pilot/s ..... Yes ❑ No

❑

(B) Station identification Morse code audio is pilot selectable for each aid and

simultaneously available to the pilot/s and instructor .... Yes ❑ No ❑

(B) Radio navigation stations available are representative of a current Australian radio

navigation chart providing realistic instrument navigation exercises .... Yes ❑ No ❑

(B) Each aid can be 'failed' from the instructor station .... Yes ❑ No ❑

(B) Radio navigation aid capability to the following specifications is available: ...... Yes ❑ No ❑

Navigation Aid Ground Stations (minimum) Accuracy

ADF Three Track ± 8°

Origin ± 2nm .... Yes ❑ No ❑

VOR Three Track ± 6°

Origin ± 2nm .... Yes ❑ No ❑

DME or GPS, indicator/s
must provide both distance
and rate of change of
distance
DME - Three Distance & Speed ± 10%

Origin ± 2nm .... Yes ❑ No ❑

LLZ One, plus an omni directional aid for orientation and to intercept final
Track ± 0.5°

Origin ± 1nm .... Yes ❑ No ❑

Glideslope One, associated with LLZ Slope ± 0.5%

Origin ± 1nm .... Yes ❑ No ❑

Marker Beacon Outer and middle,

associated with LLZ Satisfactory.. Yes ❑ No ❑

PART 2 - OPERATING CHARACTERISTICS

2.1 Effects of Controls - Aeroplanes

Flight Controls.

 Elevator:

◦ Operation and effect are conventional .... Yes ❑ No ❑

◦ Control forces acceptable.. Yes ❑ No ❑

 Ailerons:

◦ Operation and primary effect are conventional.. Yes ❑ No ❑

◦ Secondary effect is conventional .... Yes ❑ No ❑

◦ Control forces acceptable.. Yes ❑ No ❑

 Rudder:

◦ Operation and primary effect are conventional.. Yes ❑ No ❑

◦ Secondary effect is conventional .... Yes ❑ No ❑

◦ Control forces acceptable.. Yes ❑ No ❑

 Wing Flap (where appropriate):

◦ Operation and indication are conventional .... Yes ❑ No ❑

◦ Effect on performance is conventional .... Yes ❑ No ❑

 Undercarriage (where appropriate):

◦ Operation and indication are conventional .... Yes ❑ No ❑

◦ Effect on performance is conventional .... Yes ❑ No ❑

 Throttle/Power lever/s operation, indication and effects are conventional....... Yes ❑ No ❑

 Propeller control/s operation, indication and effects are conventional .... Yes ❑ No ❑

 Mixture control/s operation, indication and effects are conventional............... Yes ❑ No ❑

 Carburettor heat control/s operation, indication and effects are conventional.. Yes ❑ No ❑

 Trim/s:

◦ Operation and indication are conventional .... Yes ❑ No ❑

◦ Effective in all configurations, speeds and power settings .... Yes ❑ No ❑

◦ Any other controls operation, indication and effects are conventional .... Yes ❑ No ❑

2.2 Effects of Controls - Helicopters

Flight controls

∴ **Cyclic:**

◦ Operation and effect are conventional .... Yes ❑ No ❑

◦ Control forces minimal.. Yes ❑ No ❑

 Collective/(throttle where appropriate):

◦ Operation and primary effect are conventional.. Yes ❑ No ❑

◦ Secondary effect (yaw) is conventional .... Yes ❑ No ❑

◦ Control forces acceptable.. Yes ❑ No ❑

 Tail rotor pedals:

◦ Operation and primary effect are conventional.. Yes ❑ No ❑

◦ Secondary effect (roll) is conventional .... Yes ❑ No ❑

◦ Control forces minimal... Yes ❑ No ❑

 Undercarriage (where appropriate):

◦ Operation and indication are conventional .... Yes ❑ No ❑

◦ Effect on performance is conventional .... Yes ❑ No ❑

 Mixture control/speed select lever/s (as appropriate):

◦ Operation, indication and effects are conventional...................................... Yes ❑ No ❑

 Cyclic trim operation and effect are conventional...................................... Yes ❑ No ❑

 Any other controls operation, indication and effects are conventional........ Yes ❑ No ❑

2.3 Instrument Systems

The accuracy of the following instruments is adequate, they respond realistically to control inputs and, where appropriate, all changes in configuration, speed and power within the attitude limits of the trainer.

 ASI... Yes ❑ No ❑

 Altimeter .... Yes ❑ No ❑

 Compass... Yes ❑ No ❑

 Clock.. Yes ❑ No ❑

 VSI.. Yes ❑ No ❑

 AI .... Yes ❑ No ❑

 DG.. Yes ❑ No ❑

 T & S or Turn Coordinator .... Yes ❑ No ❑

2.4 Handling - Aeroplanes

Performance in climb, cruise and descent is conventionally related to power and

attitude .... Yes ❑ No ❑

Total drag is accurately represented with a realistic minimum drag speed (it may be

necessary to plot speed/power relationship in level flight) .... Yes ❑ No ❑

Longitudinal, directional, lateral and Dutch roll stability is adequate …………...Yes ❑ No ❑

Representative increase in elevator back pressure and corresponding decrease in

speed during level turns...Yes ❑ No ❑

Slip/skid and effect of rudder while turning is conventional .... Yes ❑ No ❑

Turns at high speed, including spiral dive effects are conventional .... Yes ❑ No ❑

Stalling, with or without power, and stall in a turn is conventional...................... Yes ❑ No ❑

Unusual attitude recovery realistic (within the attitude limits of the trainer) .... Yes ❑ No ❑

Note: If software limitations limit normal indication of any flight instrument to a limited range of pitch and/or bank, those limits become the limits of the trainer unless the trainer limits are less. A normal indication is one which an observer would expect to see in an aircraft conducting the same manoeuvre.

Indications, effects, & procedures for systems failures are conventional………..Yes ❑ No ❑

(B) Effectiveness of flight controls varies with IAS...Yes ❑ No ❑

(B) Stalling is aerodynamically simulated and dependent on angle of attack, flap setting

or configuration; stall warning is operative... Yes ❑ No ❑

(B) Power available decreases conventionally (where appropriate) with increasing

altitude .... Yes ❑ No ❑

(B) Cruise IAS decreases conventionally with increasing altitude……………..Yes ❑ No ❑

(C) Performance and flight characteristics which essentially simulate that of the specific aeroplane...Yes ❑ No ❑

2.5 Handling - Helicopters

Performance in climb, cruise and descent is conventionally related to collective pitch, power and attitude .... Yes ❑ No ❑

Total power requirement is accurately represented with a realistic minimum power speed .... Yes ❑ No ❑

Helicopter stability characteristics are adequately represented........................... Yes ❑ No ❑

Representative back stick and corresponding speed reduction in level turns ..... Yes ❑ No ❑

Slip/skid and effect of yaw control while turning is conventional...................... Yes ❑ No ❑

Unusual attitude recovery realistic .... Yes ❑ No ❑

Indications, effects and procedures for systems failures are conventional…….. Yes ❑ No ❑

(**B**) Flare effect on rotor RPM during descent is adequately represented........... Yes ❑ No ❑

(**B**) Power available decreases conventionally with increasing altitude............. Yes ❑ No ❑

(**B**) Cruise IAS decreases conventionally with increasing altitude..................... Yes ❑ No ❑

(**C**) Performance and flight characteristics essentially represent those of the specific helicopter .... Yes ❑ No ❑

2.6 Radio Navigation systems

Inter-relationship between indicated air speed, heading, ground speed and track made good is accurate .... Yes ❑ No ❑

Effect of selected wind velocities is accurate .... Yes ❑ No ❑

All aids meet accuracy requirements, *see Part 1*.. ..... Yes ❑ No ❑

ADF needle sensitivity, overhead, tracking, fail indication are conventional….Yes ❑ No ❑

VOR needle sensitivity, overhead, TO/FR, tracking and fail indication are

conventional.. . ..Yes ❑ No ❑

Flight path recorder accurately reflects ground speed and track made good from aid/s

.... Yes ❑ No ❑

(B) Indicated tracks and distances between ground stations corresponds to same route on

radio navigation chart .... Yes ❑ No ❑

(B) DME or GPS sensitivity, time/distance equation, overhead and fail indication are

conventional... Yes ❑ No ❑

(B) LLZ needle sensitivity, tracking and fail indication are conventional ....Yes ❑ No ❑

(B) Glideslope needle sensitivity, tracking and fail indication are conventional Yes ❑ No ❑

(B) Glideslope relationship to altitude, DME or GPS and marker beacon/s are

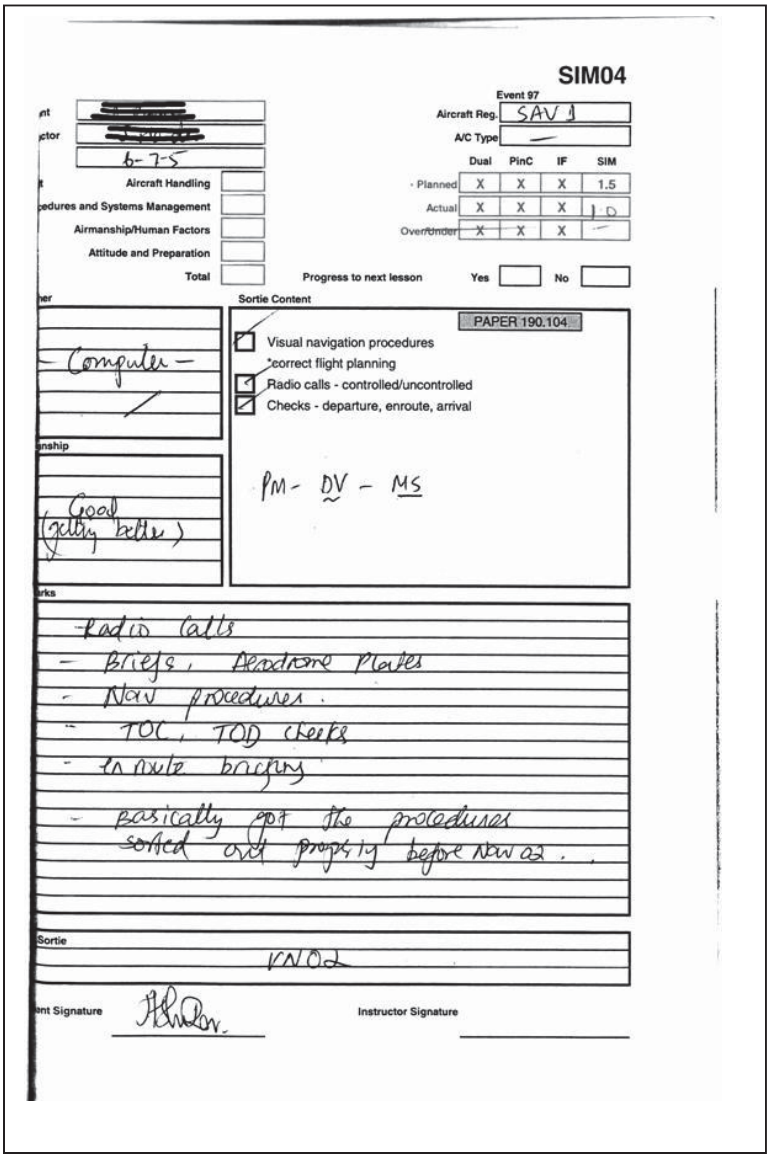
accurate…………………………………………………………………. Yes ❑ No ❑

(B) The flight path display is accurate to ±5 degrees for tracking and ± 10% in distance

flown.. Yes ❑ No ❑

APPENDIX J: Stage 3 PCATD Navigation Procedures

SIM04 Assessment Sheet



SIM04

Event 97

nt	[redacted]
ctor	[redacted]
	6-7-5

Aircraft Reg. SAV 1

A/C Type —

	Dual	PinC	IF	SIM
Planned	X	X	X	1.5
Actual	X	X	X	1.0
Over/Under	X	X	X	—

Aircraft Handling

edures and Systems Management

Airmanship/Human Factors

Attitude and Preparation

Total

Progress to next lesson Yes No

her

— Computer —

Sortie Content

PAPER 190.104

Visual navigation procedures

*correct flight planning

Radio calls - controlled/uncontrolled

Checks - departure, enroute, arrival

PM - DV - MS

nship

Good (getting better)

rks

- Radio calls
- Briefs, Aerodrome Plates
- Nav procedures.
- TOC, TOD checks
- en route briefing
- basically got the procedures sorted out properly before Nav 02.

Sortie

VN02

nt Signature

Instructor Signature

Figure J1. Navigation SIM04 Assessment Sheet

APPENDIX K: NZ Army PCATD (PPL Training)

Figure K1. NZ Army UAV/UAS (KAHU)

Source: (NZ Army KAHU, 2008)- NZ Army UAV (KAHU) Retrieved from http://www.flickr.com/photos/nzdefenceforce/6006386029/

Figure K2. UAV Pilot Trainee PCATDs for PPL Training

APPENDIX L: Letter of Invitation to Comparative Study

Savern Reweti
School Of Aviation
Massey University

Date

Dear __________

My name is Savern Reweti. I am a lecturer at the School of Aviation., Massey University and I am currently studying for my PhD. The purpose of this letter is to invite you to participate in a research project I am, conducting as part of my doctoral studies.

The title of my thesis is “PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures: Development, Validation and Effectiveness

I am looking for volunteers who have has some flying experience up to and including PPL standard to come to the Massey School of Aviation Flying Centre or Ardmore Flying School for approximately two hours to participate in a series of Visual Flight Rules training sessions in the SAV2 PCATD and the Frasca TruFlite FTD. The VFR lesson will consist of a 10-15 minute familiarisation of the FTD or PCATD you will be assigned to fro training. Following the familiarisation session, you will complete three 20-minute VFR practice sessions and a final 10-15 assessment session in the Frasca TruFlite FTD. There is no cost to participate in these sessions but you will have to provide your own transportation to the flight centre.

There is no risk to your pilot training or your current pilot qualification and all data collected will be confidential.
Your name, address, pilot experience, responses on the Pilot Questionnaire, and experimental results will be coded with a random reference number to protect your confidentiality.

Participation in this experiment should improve your competency in VFR procedures and I will endorse this simulation practice in your logbook. Your participation in this study is strictly voluntary. You may choose to withdraw your consent to this research or cease participation at any time without penalty.

If you have any queries regarding your participation in this study, please feel free to contact me at 0272059552. My email address is S.Reweti@massey.ac.nz. Dr Lynn Jeffrey is my primary supervisor and Dr Andrew Gilbey is my secondary supervisor and you may contact them at the School of Aviation, Massey University if you have any concerns. If you would like to participate in this study, I request that you complete the Participant Questionnaire and Consent Form and return to me in the envelope provided. I look forward to your participation in this research project.

Yours Faithfully
Savern Reweti

APPENDIX M: Informed Consent Form

Research Title

The title of my thesis is "PC-Based Aviation Training Devices for Pilot Training in Visual Flight Rules Procedures;: Development, Validation and Effectiveness
"

Researcher
Savern Reweti
School of Aviation
Massey University
Palmerston North

S.Reweti@massey.ac.nz

Phone:

Mob:

I have been informed about the procedures for participating in this study as detailed in the cover letter.
YES _______ (please initial)
I am willing to participate in this research project
YES _______ (please initial)
Participant's Name (please print): ____
Participant's Signature: _______________
Date: _________________

Please sign and date both copies of this informed consent from , return one copy to me and retain one for your records
Savern Reweti

APPENDIX N: Participant Questionnaire

I fully expect that the participants in this research project will have a wide variety of flight training experience. To assist with interpreting the results of this study I require some information about your flying experience. Therefore, I would like you to fill out this questionnaire and return it to me including the Informed Consent form and the Participant Questionnaire, in the envelope provided

Your answers will help me to identify the experience level of each participant in this study. All answers will be confidential and will be coded with a randomly generated reference number and will not be linked to your name

Name ___________________________ Date ___________

1. Do you hold a Private Pilot's Licence? __________

2. What is your total accumulated Flight Time? ________

3. What is your total accumulated VFR Time? ________

4. What is your total accumulated FTD Time? ________

5. What is your total accumulated PCATD Time? _______

6. What is your total accumulated Recent Flight Time (last 30 days)? ______

7. What Aircraft Type Ratings do you have? ______________________

8. What type of aircraft do you usually fly? _________________________

APPENDIX O. Diamond DA 40 PCATD

Figure O1. Massey University School Of Aviation Diamond DA 40 Panel (Real)

Figure O2: Diamond DA 40 Motion Based PCATD

Figure O3. Diamond DA 40 PCATD Triple Screen Display

Figure O4. Student Pilot & Prime Minister of NZ Flying PCATD

APPENDIX P. Customised NZ Terrain (MSFS Compatible)

Figure P1: Example of Vector Land Class NZ Terrain

Source: (VectorLandClass, 2012) - "VLC Screen Shot." Retrieved from http://www.vectorlandclass.co.nz/index.php/media/screenshots.

Figure P2. Example of Customised NZ Scenery -Masterton Airport

Source: ((Botica, 2012)- Masterton NZMS. http://nzff.org/forum/index.php?showtopic=12374&hl=masterton

APPENDIX Q. Motion Platform Technology

Figure Q1. Hexapod 6 DOF Flight Simulator

Source: (Arnold, 2004) -Lufthansa Flight Simulation 6-DOF Stewart Motion Platform
http://commons.wikimedia.org/wiki/File:Simulator-flight-compartment.jpeg.

Figure Q2. Diamond DA 40-Construction - CKAS 2DOF Motion Platform

APPENDIX R. PCATD Replica Garmin PFD & MFD

Figure R1. PCATD Glass Cockpit Primary Flight Display (PFD)

Source: (Flight 1 Aviation Technologies, 2011). "Garmin G1000 Student Simulator. Retrieved from http://www.flight1tech.com/Products/GarminG1000StudentSimulator.aspx.

Figure R2. PCATD Glass Cockpit Multifunction Flight Display (MFD)

Source: (Flight 1 Aviation Technologies, 2011). "Garmin G1000 Student Simulator. Retrieved from http://www.flight1tech.com/Products/GarminG1000StudentSimulator.aspx.