Transference of PC-based simulation to aviation training: issues in learning

A review of the literature 1997-2007

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Section 1 Executive summary

The use of flight simulation devices as learning tools for aviation training is well established – particularly in the training of commercial pilots and airline flight crew. The emphasis within this field has largely been on sophisticated and costly cockpit simulators that provide high-fidelity, highly-immersive learning environments.

With the rapid emergence of the personal computer and the Internet, the computing power to run reasonably sophisticated simulation software has become available and continues to grow exponentially. Feature-rich simulation software and compatible hardware devices have become prevalent, providing the general public with low-cost access to flight experiences. This has led to individuals using PC-based simulators as introductions to, and pre-training for, real-life flying training. Some already licensed pilots, flight instructors and training institutions have also taken up the tool for use in part-task, self-directed and classroom-based training.

With the rapid uptake of PC-based simulators, the aviation industry and regulators have posed questions regarding the validity, effectiveness and risks associated with the use of the tool in formal training. Various research studies and reviews have been conducted and there is a relatively small but growing body of literature on this topic.

PC-based simulators have a positive role to play within aviation training at all levels. The literature reveals that there is a positive transfer-of-training from the simulator to real aircraft and in-flight-training for part-task training, procedural training, to teach underlying cognitive principles, and for tasks that are new and/or sequenced early in training programs. They are also effective for recurrent training and advanced instrument flight procedure training and ongoing pilot proficiency / practice. PC-based simulators offer a superior learning environment to an airplane in some contexts, and there are significant time and cost savings to be realised. However they are not as effective, and sometimes detrimental, to the teaching of basic flight handling and maneuvers. Their relative lack of fidelity can mean poor habit formation and increased training time due to skills and procedures needing to be relearned.

A key finding is that PC-based simulators have a peak transfer-of-training efficiency, and using them beyond this level in training will mean decreasing effectiveness and time/cost inefficiency. Finding the peak level and a balance between simulated and in-flight training for each major area of flight training is critical. So too is the continuing role of flight instructors who provide a fundamental coordination and supervision role, and can assist in the integration of various training tools and methods.

Balance is also required in how PC-based simulators are used within training programs. They should be creatively used as multipurpose tools for relevant aspects of training, rather than as fully-fledged flight simulators – which clearly they are not.

To find this balance and to improve the design of PC-based simulators and the curricula that they are used within, more focus needs to be given to educational theory, design and practice. There is a largely unchallenged focus in the aviation industry on improving the technical and fidelity aspects of simulators as the answer to improving training, rather than upon learning outcomes and the learning process itself. To support this, aviation educators, instructors, and software designers need to work in partnership with educational practitioners to produce more creative, innovative and informed learning designs that leverage technical and educational advances. It is these designs that can realise the further potential that PC-based simulators offer the aviation training field.

Section 2 Introduction

2.1 Introduction

The use of flight simulators to train pilots is, in itself, not a new phenomenon. Simulation began to emerge in the pioneering era of aviation, and was spurred on by World War II. As electronic / information technology increased exponentially in speed, power and availability in the later part of the 20th century, the scope and use of simulation in pilot training has grown steadily and is now an integral part of professional pilot training, and to a lesser extent – private/recreational pilot learning and training.

The rapid development and pervasiveness of technology has spawned a parallel industry and community in the field of flight simulation. With personal computers (PCs) becoming ubiquitous in recent years, and with exponential increases in PC power and speed, the humble PC has emerged as a platform that can support reasonably sophisticated aircraft simulators. Software and hardware manufacturers began to leverage this potential late in the 20th century and this industry has grown into a significant field, with a growing community of users globally.

Some users of PC-based flight simulators are / or were licensed pilots, or have later become licensed pilots. It is not surprising then that the PC-based flight simulator has been used for self-managed learning – providing introductory learning experiences, and a platform for learning review and practice. But from this relatively minor and non-professional role, the PC-based flight simulator has grown in complexity, accuracy and availability in the past two decades to a point where educators and regulators in the aviation field have had to pay increased attention. Indeed, some instructors and training organisations now use PC-based simulators as part of their formal training approaches.

However, the potential and validity of PC-based flight simulators is by no means universally accepted or appreciated in the aviation field. There are wide variations in attitudes to, and acceptance/use of the technology as a platform to assist in the training of pilots. Furthermore, there is a wide spectrum of opinions on what the advantages of PC-based flight simulator are for trainee pilots, and what the pitfalls and possible dangers are.

2.2 Research questions

This review will examine contemporary literature focused around the following issues and questions:

- In what contexts and for what applications are PC-based flight simulators currently used?
- In what training contexts do PC-based flight simulators provide the greatest and the least transfer-of-training benefit?
- What are the potential improvements that applied learning theory can bring to this field?
- What questions and issues remain for further investigation?

There are various meta-reviews and literature reviews already in existence that discuss some of the questions/topics listed above. However, this review has been prepared to examine these questions critically from the perspective of educational design and theory. The intention is to inform emerging frameworks for practice in aviation training, in order to increase the effectiveness of PC-based simulation as an educational tool within this field.

2.3 Overview of the literature

The review of literature commenced with wide ranging searches for scholarly journals, papers, reports and theses; together with an industry focused search for articles, books, training information and general web resources. Further information on the methods and criteria used to search and select the literature can be found in Appendix A.

The quantity of literature sourced for this review is relatively small and has been published mostly from 1997 through to 2007. Most of the academic literature was sourced from the United States where many of the world's largest academic aviation departments / institutions exist. It must be said that the level of collegiality from many of these institutions in supplying assistance for this review was generally disappointing.

The literature that is publicly available from the aviation industry itself appears to be sparse and variable in scope and rigor. There is considerably more literature from the broader field of professional flight simulation for the training of airline flight crew, but less on the use of PC-based simulation for introductory or part-task training in general aviation. In general, commercial simulation manufacturers and simulation-based training providers seem to publish little in the way of publicly available information that adds to the body of knowledge in the field.

Given these conditions it has been a challenging task to source literature for this review. This affects the depth of analysis currently possible, and points toward considerable scope for further research.

2.4 Fundamental terminology

Throughout this review a number of terms and acronyms are used to describe major classes of flight simulators. There are variations on these between countries and regulatory authorities, but these terms have been generalised here for readability.

Full Flight Simulator	FFS	A highly specialised and high fidelity environment which simulates the form, fit and feel of a specific real aircraft cockpit – including visual and motion systems. Advanced FFSs can be used for up to 100% of aircraft type training time, in some contexts.
Flight Training Device	FTD	A static device made with custom software/hardware that is designed to replicate a generalised or specific-aircraft cockpit environment. Not as sophisticated or comprehensive as a FFS. Often used for professional training and can be used to fulfill parts of formal pilot training and flight-time requirements.
Personal Computer-Based Aviation Training Device	PCATD	Software that runs on a personal computer (e.g. Windows or Apple based), which provides a partial or comprehensive flight simulation environment on screen. This includes off-the-shelf flight simulator software. The software may be augmented with specific hardware devices such as consoles or flight controls.

PCATDs are the major focus of this paper and the term is used interchangeably with ‘PC-based simulator’.

Section 3 Historical and technical context

3.1 A brief history of flight simulation

The emergence of aviation has been both rapid and pervasive – growing from the tentative beginnings of the Wright Flyer in 1904 through to the large and diverse industry we know today. Within this century of development various service, support and related fields quickly emerged – including flight simulation.

In the years immediately following the Wright's first powered flight, it became obvious that initiating pilots to flying aircraft in the air was both risk-laden and costly. Early attempts to mitigate this focused on harnessing real aircraft to static devices that allowed pilots to manipulate the flight controls and observe effects – in a rudimentary fashion (Watkins & Marenka 1994, p. 22). Even at this early stage the limitations of simulation versus in-flight pilot training were debated.

The first flight simulators emerged in the 1920s (Koonce & Bramble 1998, p. 277), the most notable of which is the Link Trainer created by Edwin Link. This first generation simulator was a scale mock-up of an aircraft with a single-person cockpit, instruments, controls, and basic movement provided by hydraulic actuators (AOPA 1998, p. 1). The Link Trainer was used mainly for instrument flight training.

The armed forces, particularly in the United States, saw the potential of simulators during the 1930s and used them to train pilots to fly on instruments, i.e. without visual reference to the ground (Watkins & Marenka 1994, p. 23). Many pilots were required and the trainers became pivotal in the rapid training of pilots for the burgeoning mail routes, and for combat pilots in preparation for World War Two which loomed towards the end of the decade.

World War Two caused a significant rise in demand for new pilots throughout the world. Simulators such as the Link Trainer became integral in the basic training of new pilots. During the war many new aircraft types were introduced and specialised simulators that replicated their cockpits were introduced (Watkins & Marenka 1994) to streamline training and reduce costs and risks.

After World War Two the fledgling flight simulation industry turned to the airline industry as its prime market (Koonce & Bramble 1998, p. 278). Spurred on by the technological improvements of World War Two - high performance, sophisticated aircraft that could fly in all weather were becoming the norm. Competent pilots and the training systems to support them were in increasing demand. The majority of simulators produced in the decades after the war were therefore designed for the high-end airline market. These increasingly sophisticated and costly devices were generally not affordable or suitable for the general aviation sector (Koonce & Bramble 1998, p. 278).

During the second half of the 20^{th} century the information technology industry was also developing rapidly. With the availability of analogue computers came the ability to calculate and replicate complex aerodynamic and aircraft performance algorithms. In turn, aircraft manufacturers and simulator developers were able to construct increasingly sophisticated devices the simulated the performance and fidelity of specific aircraft (Watkins & Marenka 1994, pp. 50-51). Basic visual representations and higher-fidelity motion platforms began to emerge.

As the digital age dawned in the 1960s and 1970s airlines were driving the demand for high-fidelity simulators and championing the transfer-of-training effectiveness of simulator-driven training programs (Koonce & Bramble 1998, p. 280). Digital processors were growing exponentially in speed and capacity, providing developers with platforms to produce high-fidelity external views, weather representations, sound, and motion. Aviation regulators across the world began to accept simulator training time as equal to time in the actual aircraft. This has continued to increase in parallel with the quality of simulators, to the point where, as Caudrey (2004, p. 3) notes with some trepidation:

> ... we do have pilots authorized to fly zero flight time who can legally move to the left seat (Captain position) who have never actually flown the aircraft. They have been Certified Zero Flight time in the Simulator.

Given the seemingly limitless potential of the digital era and the high-fidelity it has brought to simulation, it could be said that flight simulation has now come of age. The flight simulator certainly has become a mainstay of pilot training – particularly in the airline industry. Transfer-of-training effectiveness and cost savings are well established advantages of flight simulation, and this has firmly embedded their use in training programs. Yet the debates surrounding how flight simulators can be used most effectively, and the extent to which they should be used in aviation training continue - much as they did, in essence, in the pioneering era of aviation.

3.2 Emergence of PC-based flight simulators

The emergence of the personal computer in the late 1970's spawned a revolution in computing, as the general public were given the opportunity to afford and use computers for the first time. The personal computer became a platform for many new innovations in information technology – a phenomenon that has exceeded the expectation of the early developers.

It was on this platform that the first flight simulators emerged for personal use. In 1980 the preeminent pioneer in this field, Bruce Artwick, released a flight simulator which ran on the TRS80 and AppleII computers. Even at this early stage in personal computing history, this rudimentary simulator leveraged the limited power of these PCs to an astonishing level. This first generation was the beginning of a persistent development process which continues to the present day. In 1982 Microsoft began to distribute the software and since that year ten major versions of the software have been released (Grupping 2007a). The current version – Flight Simulator X – boasts state-of-the-art features that demonstrate how far the humble personal flight simulator has come since the crude black-and-white line graphics and simplistic aircraft of version one. The latest version provides a sophisticated 3D global environment for flight with highly detailed 3D rendering of aircraft and global scenery, over 20,000 airports, highly-sophisticated aircraft panels and systems, authentic flight, sound and visual modeling, artificially intelligent air-traffic-control, secondary aircraft and dynamic objects, dynamic weather and environmental effects, and a large database of aircraft types to choose from (Microsoft 2007).

While Microsoft's Flight Simulator became the most popular title, there were other notable simulators developed – such as Terminal Reality's *Fly* series, the *Flight Unlimited* series from Looking Glass Studios, and *ProPilot* from Dynamix. Many of these other simulators are no longer in production yet they are still in use and have contributed much to the development of PC-based flight simulation.

Another notable simulator, which is gaining in widespread use, is *X-Plane* from Laminar Research. This software has pushed the boundaries of PC-based simulators to many new levels. The developers claim that 'X-Plane is the most thorough, flexible, and realistic flight simulator available for personal computers…' (X-Plane 2007a). The sophisticated flight modeling in the software has such high fidelity that it has become certified by the United States Federal Aviation Administration (FAA) for use in flight training towards Commercial Certificates, Instrument Ratings, and Airline Transport Pilot Certificates - when used in a full-motion simulator environment driven by X-Plane software (X-Plane 2007b).

Open-source simulators have also entered the field. *FlightGear* is an open-source solution supported by a group of aviation enthusiasts. Their goal is to develop an open and extensible platform for research, development, and end-user experiences (Binder 2005). This flexible platform fills an important gap that commercial simulators do not meet.

With the affordability and availability of PC-based flight simulators, the user-base and user community has grown to significant levels throughout the world. Statistical data to support this is not readily available in forms that can be reliably analysed, however the following information provides a generalised view of growth and use.

Lenferink (2007) reports that until 1999 over 21 million copies of Microsoft Flight Simulator had been sold – this had grown from 4.5 million copies in 1997. Unfortunately no further data can be obtained on sales figures, however with four major releases since 1999 the accumulated sales figure would be significantly higher. The Gamespot website (Gamespot 2007), which has comprehensive user ratings and rankings of software titles, ranks the previous version of Microsoft Flight Simulator [version 2004] within the top 3% of all 38,873 game/simulation titles in PC history.

An industry has emerged to support flight simulator users with add-on software to enhance the user experience and the fidelity of the simulators. These include add-on aircraft, scenery, panels, tools, flights and so forth. A list compiled by MiGMan (2007) shows 65 active companies selling add-ons around the world.

A large user community has also developed, supported primarily by various internet portals. These websites provide forums, articles, reviews and extensive libraries of free add-ons submitted by users. Of these portals the largest appear to be AVSIM.com and FlightSim.com. AVSIM reports 656,246 registered library members (AVSIM 2007), and FlightSim.Com reports over 500,000 members (Anderson 2007, pers. comm. 01 June).

The use of PC-based flight simulators has also grown significantly in multiplayer online environments. Multiplayer networks provide internet connectivity and software for virtual pilots and virtual air-traffic-controllers to interact and have shared virtual-presence in a sophisticated virtual world. The two main networks – the Virtual Air Traffic Simulation network (VATSIM) and the International Virtual Aviation Organisation (IVAO) are reported by Lenferink (2007) to have over 130,000 members in total. Jenkins (2007, pers. comm. 10 Sep.) recently reported that virtual pilots have flown over 10 million hours on the VATSIM network since it began in 2001.

From humble beginnings in 1980, use of the PC-based flight simulator has grown significantly. The high-fidelity and feature-rich software of today's simulators, together with the extensive global user base, is testament to the popularity of the software. It is not surprising then that the PC-based flight simulator has become a well-known and popular tool in the field of aviation, and is now used in the field in a variety of ways – as described in the sections that follow.

3.3 Regulatory context

Much of the literature in this review pertains to flight training in the United States (US) and therefore the regulations of the Federal Aviation Administration (FAA) in the US are a feature. Other countries and regions have their own regulatory bodies, such as the Civil Aviation Safety Authority (CASA) in Australia, and the Joint Aviation Authority (JAA) which is a combined authority across Europe. The FAA and JAA regulations regarding the use of simulators in flight training are generally similar, and seem to represent a general level of global standardisation – however a detailed discussion on this topic is beyond the scope of this paper.

It is worth noting that while some standardisation exists there are variations which cause some difficulties in cross-recognition of simulators across the world. Terminology and classification of simulation devices is certainly one of these – as discussed by CASA (2002). In their proposal for regulatory change CASA outlines various options for reclassifying simulator types to better align them with training needs, and further alignment with FAA and JAA standards is put forward as a preferred option (p. 16). In 2006 CASA implemented several key changes (CASA 2006) including the adoption of three main categories – Synthetic Trainer, Flight Training Device (FTD), and Flight Simulator. PC-based simulators fall into the Synthetic Trainer Category. Several changes were made to further align Australian regulations with the FAA and JAA.

As a general introduction to how PC-based simulators are permitted for use in formal training, the current FAA regulations (FAA 1997) allow PCATDs that have met minimum hardware and software requirements to be used for:

- Logging time towards an instrument rating – within an integrated ground and in-flight training curriculum (with an instructor). This is limited to no more than 10 hours of the allowable time that can be accumulated in simulators. Instrument rating tests cannot be conducted on a PCATD.
- More advanced PCATDs types such as the Basic Aviation Training Device (B-ATD) and Advanced Training Device (A-ATD) allow for increased time – such as the conduct of instrument proficiency checks, 10 hours toward initial instrument ratings, and 2.5 hours towards private pilot certificates.

According to Williams (in McDermott 2005, p. 23) the FAA has been somewhat resistant to industry pressure for training time in PCATDs to be given greater recognition and equivalence in formal training. Prominent aviation training institutions have called for PCATDs to be given similar status as FTDs, yet there does not seem to have been any regulatory move towards this at this point in time.

Section 4 Applications of PC-based simulation for aviation

As seems to be the case with many technologies, the technologies themselves have been used, developed, and added-to by third parties and users in ways that the original developers may never have contemplated, or had only dreamed of. This is the case with the PC-based flight simulator. Its uses are many and varied, from simply an entertaining game through to a sophisticated educational tool for the aviation industry.

In this section selected examples of the use of PC-based flight simulators are provided. A comprehensive range of examples is beyond the scope of this paper.

4.1 Entertainment

Despite the title *Flight Simulator*, the earliest creations from Bruce Artwick and the SubLOGIC Corporation began their existence as part of the PC gaming revolution. The developers were obviously intent on developing a sophisticated simulator (Grupping 2007b), but were limited by the technology of the time. Conversely, the PC-based simulators of today may well have exceeded all expectations and have obviously moved beyond the gaming market – as pointed out by AOPA (1998):

> Borrowing from the computer game industry, several software writers have created programs that simulate instrument flight so well that anyone seeking an instrument rating should consider using one during training.

The training aspects of PC-based flight simulators are the primary focus of this paper, however it should be acknowledged that while training with these devices is now possible, flight simulator software is still used by many purely for personal entertainment and gaming. Indeed, there is another significant pool of developers and users in the field of military flight simulators – which are beyond the scope of this paper.

It has not been possible to determine the comparative usage levels of flight simulators for entertainment versus training. However, a reasonable hypotheses on the interrelationship between the two user-bases is that some users move from using their simulators for entertainment to using them for focused learning, and, some users go on to obtain Private Pilot Licenses (PPL) and enter into professional aviation careers (Williams 2006, p. 1). This is supported in a survey of users by

AVSIM (2006) where users were asked ‘If you are not a pilot, do you want to become one in the future?’ Of the 3510 responses, 47% indicated a response in the affirmative, while 22.1% of users indicated that they already had a current or lapsed PPL.

4.2 An informal learning tool

Before discussing PC-based simulators in the context of informal learning it is appropriate to outline some theoretical basis for this type of learning.

Learning, in general, does not occur only within the context of formalised and/or institutionalised education. Humans also learn by a multiplicity of informal methods such as personal experience, from observation, by vicarious means, through experimentation, through trial-and-error, and, through self-directed learning (Burns 1994, pp. 99-100).

Self-directed learning, as summarised by Burns (1994, p. 258), is characterised by three essential elements:

- there is no prescribed content that must be transmitted to the student,
- the content and the way the content is determined by the interests and needs of the student, and
- what the student derives from it is determined by the extent to which they attain their own learning objectives.

Self-directed learning is well supported in educational literature (Brookfield 1986; Rogers 1969) as a theory and practice of learning that is better suited to the way adults learn, in contrast to teacher-directed learning commonly used to teach children. Burns (1994, pp. 235-236), in summarizing a number of theorists, asserts that adult learning theory is based on five key concepts:

1. Adults need to know why they are required to learn something before being motivated to learn.
2. Adults are individually responsible and prefer to be self-directing.
3. Adults are unique – based on their individual life experiences – and therefore have varying learning needs and preferences.
4. Adults are task- and problem-centered in their approach to learning.
5. Adult motivation for learning seems to be intrinsic – derived from various core human needs, and supported by the intrinsic human desire to grow and develop.

The concepts underpinning self-directed learning (by adults) are relevant to this context. Non-pilots, trainees, or current pilots who use PC-based flight simulators for self-directed learning have an intrinsic motivation to learn, have unique learning needs, and have specific learning tasks to achieve. Simulators offer learners the flexibility to choose where and when they learn, what they learn, and at what pace they learn (Watkins & Marenka 1994, pp. 36-37).

Williams (2006, p. 2) lists that those who can benefit from using a PC-base simulator for self-directed learning:

> …student pilots who want to enhance book learning and review specific concepts and skills ... certificated pilots hoping to complement their real-world flying… instrument rated pilots looking for ways to add interactivity to their IFR theory studies … [and] virtual aviators who want to learn more about real-world flying.

More specifically, in the 2002 version of Microsoft's *Flight Simulator*, significant new features introduced were the learning centre, virtual flight instructor, interactive flying lessons, interactive tests, and flight challenges – all at varying levels of competency and difficulty (Binder 2005, p. 18). These features have been expanded and refined in later versions, which indicates a significant trend in the increased use of the software as an informal learning tool.

4.3 A tool for formal part-task training

The use of PC-based simulators for training in specific pilot tasks / competencies has grown steadily since they became available, and is now included in the curricula of various pilot training programs and schools (Williams 2006, pp. 15-16).

In this context professional theory instructors and flight instructors typically use simulators to train students on specific tasks, and allow students to practise and develop their competency in those tasks (AOPA 1998). Common tasks in this context are navigation, basics of flight controls, use of flight instruments, instrument flight, and the use of avionics and radio equipment (Talleur et al. 2003).

The US Navy has, since 2000, been using PC-based simulators for part-task training as part of their curriculum: 'Flight Simulator allows students to learn and practice basic procedures, such as cockpit control manipulations and navigation before they get into any airplane' (Dunlap in BaseOps.Net 2007).

PC-based simulators are also used for part-task training in learning labs. At Flightsafety Academy in Florida – a major US aviation training institution – students complete 27 hours of instruction using Microsoft Flight Simulator in a computer lab environment (Binder 2005, p. 18). Flightsafety emphasise however that this form of learning is applicable to specific tasks only, and not the complete training program (BaseOps.Net 2007).

In these contexts, and more-so in the larger training organisations, simulator part-task training is often combined with other interactive and/or self-paced elements such as CD/DVD self-paced courses and software learning aids (Williams 2006, p. 21). Screen images and video clips taken from flight simulators are also used to add to the multimedia richness of these resources.

4.4 A classroom aid for formal training

Williams (2006) contends that PC based simulators should not only be used as cockpit replicas for training, but should also be used in more interactive and focused training contexts – including the classroom. Simulators can be used in one-on-one teaching contexts around a PC screen and in small or large group contexts with the simulator visuals projected onto a large screen.

Examples of this as an aid for classroom training include demonstration / presentation of:

- specific equipment, procedures and tasks
- flight instruments and effects in context
- flight controls / surfaces and effects in context
- navigation concepts and practice (Williams 2006)
- various flight scenarios with discussion of cause and effect
- pre-flight and post-flight briefings (Collins 2000)
- Advanced situational awareness training in airline crew flight training programs (Homan 1998)

4.5 A tool for research

In their review, Koonce & Bramble (1998, pp. 262-263) report various general uses of PC-based simulators for research including human factors and pilot performance research, a platform for instrumentation testing and development, crew resource management (CRM) research, and crew coordination and training research.

Binder (2005, p. 20) reported on the development of the *FlightGear* PC simulator that is being developed as a sophisticated research tool for academic purposes and as a test-bed for innovations. The ADC (2007) describes the acclaimed *X-Plane* simulator as a platform where '… companies can "load" a plane under development into X-Plane and find out how it will fly even before it is built, making engineering faster and easier.'

In sections five and six (to follow) various research studies are discussed that have used PC-based simulators to conduct experiments in aviation training.

Section 5 PC-based simulators: issues in aviation training

Given the rapid rise of the PC-based flight simulator, its prevalence amongst the general public and the aviation community, and its various uses; there are not surprisingly a wide range of attitudes to, and uses of these devices within the aviation community.

Various questions arise regarding the validity, effectiveness and usefulness of training undertaken with PC-based simulators and how this transfers to formal training conducted in an aircraft, and to the ongoing proficiency of pilots. These questions are relevant across the aviation training spectrum – from basic recreational general aviation training through to advanced airline transport pilot training.

Therefore, what are the advantages of using PC-based flight simulators in this context? Do they provide effective transfer of training, and do they reduce costs? And what are the disadvantages, pitfalls and risks? The review in this section will focus on these questions.

5.1 Introduction

The literature discussed here has been sourced mainly from the period 1997 to 2007, with the aim of presenting a contemporary review.

Safe and efficient piloting requires a complex skill-set involving the interdependent application of a diverse range of knowledge, principles and psychomotor skills. Studies in this field are therefore focused on a range of these skills, although it seems that there are many specific areas of skill yet to be studied.

In broad terms there are a number studies and meta-reviews in the field that present some evidence of a positive transfer of training from PCATDs to aircraft-based training and to ongoing pilot proficiency. Some of these identify specific aspects of aviation training where there is positive transfer, and specific aspects where there is negative transfer or no significant difference. These aspects will be discussed in this section.

It is worthwhile noting at this point some of the difficulties found in the research literature in this field. Rantanen and Talleur (2003), in their broad review of 19 studies from the past 56 years which have investigated transfer of training effectiveness from ground trainers to airplanes, revealed that it is difficult to make definitive conclusions about the best use of these devices. They highlight a number of intervening variables and issues within the studies which create a lack of valid data and wide variance in the results and conclusions. Prevalent intervening variables are the attitudes of the participants and instructors, variation in prior/current knowledge or participants, subjective data gathering methods, relatively small groups of participants, and the difficulties of conducting controlled experiments in a dynamic aviation environment. These variables and issues present significant challenges to the conduct of sound research on this topic, and this review should be read in context with these limitations in mind.

5.2 Transfer of training

Transfer of Training is a concept in learning theory that describes the transfer of existing learning or skills from one learning context or environment to another (Roscoe & Williges 1980). A positive transfer is seen when the development of new skills is positively derived from pre-existing skills (Macchiarella, Arban, & Doherty 2006, p. 301). Negative transfer of training is seen when pre-existing skills have a detrimental effect on new skill development (Roscoe & Williges 1980).

The use of mathematical ratios to quantify the nature of the transfer of training from simulated learning environments to actual workplace environments is prevalent in the literature in this field. A brief introduction to these is pertinent at this point.

- *Percent Transfer* (PT) is a relatively simple measure of time savings in airplane training that can be made by using simulators for ground training (Taylor et al. 1999, p. 321). However this does not take into account the amount of time spent in training.

- *Transfer Effectiveness Ratio* (TER*)* takes into account the time spent in simulator training and the bearing of this on subsequent time savings in training in an airplane. TER is the difference in the number of iterations taken by an experimental group to reach competency in a task, in comparison to a control group (Macchiarella, Arban, & Doherty 2006, p. 301).

It is important to note that increased simulator training time will typically increase the *percent transfer* but will decrease the *training effectiveness ratio* (Taylor et al. 1999, p. 321; Alexander et al. 2005). This indicates that to maximise the effective transfer of training a balance should be found between time spent in simulator-based training, and time spent training in an aircraft. This issue will be further discussed in section six.

5.2 Environments for learning

There are significant differences in the nature and dynamism of learning environments in this context. A PCATD in a room is a significantly different environment than the cockpit of a real airplane (Landsberg 2002)

Williams 2006 (p. 28) points out that pilots who have undertaken much of their early learning with a PCATD can be influenced by a condition known as *state dependent learning* where they have:

> learned about flying fundamentals in a "simulated" state (a calm, relaxed, home environment). When placed in the cockpit of a real airplane, however, they try to apply that knowledge while bombarded by a new set of potentially overwhelming stimuli.

However there are also disadvantages of the airplane based learning environment:

- A generally poor environment for teaching.
- Noisy and difficult to converse well.
- A dynamic environment that cannot be 'paused'.
- Risks and unwelcome complications of real-life flying.
- Expensive – aircraft hire is a significant cost.

(AOPA 1998; Landsberg 2002)

PCATDs, on the other hand, have their advantages:

- A generally quiet and controllable environment.
- Task isolation – students can concentrate on one aspect of flying at a time.
- Ability to pause the simulation for review and correction.
- Ability to track and review performance –for example recording and view aircraft track and performance variables.
- No in-flight safety risks.
- Much lower costs.

(AOPA 1998; McDermott 2006)

5.3 Cost and time savings

Another prominent issue in the literature, which is related to the learning environment issue (above), is the notion of time and cost savings (AOPA 1998; Taylor et al. 1999; Williams 2006). On a pure cost-comparitive basis PCATDs have a significant advantage here, but does the use of PCATDs translate into time and cost savings overall?

Landsberg in McClusky (2003) seems to be in no doubt on this question:

> Over the years, it's evolved phenomenally. It's my observation that someone wanting to become a pilot could save some considerable time and money by using Flight Simulator before starting flight lessons

Research by Emanuel (1997) concurs with this. He found that there was significant time and cost savings when comparing students undertaking instrument training who were prepared using a PCATD with those who did not. Students who were trained in part with PCATDs took less time to attain proficiency in many tasks and required less time in the real aircraft to undergo training and testing.

Taylor et al. (1999) also a found a significant reduction in course completion times for a group trained using simulators in comparison to a group which did not. They concluded that there is a potential reduction in training costs when PCATDs are utilised.

However Taylor et al. 1999 (p. 333) caution that PCATDs can actually cost users more if used inappropriately. If the amount of time on simulator based training goes beyond the peak TER level then there is likely to be more in-flight training required, and therefore higher costs. This highlights the importance of determining the optimum level of PCATD use, and the sequencing of that use within a training program.

5.4 Issues in basic flight training

One of the most prevalent debates within this topic amongst the aviation community surrounds the fundamental use of flight controls and general airplane handling. PCATDs have generally low fidelity in this regard with simplistic control yokes or joysticks that often lack the control feel and control loading of a real aircraft.

Dennis & Harris (1998, p. 264) hypothesized that '…ab initio trainee pilots would perform better if they were able to review previous flight lessons and preview the maneuvers in the forthcoming flight using a DTS [desktop simulator]'. This was based on their assertion that PC-based simulator training could be used effectively as an adjunct to training in the air (p. 263). This is despite the known limitation of the poor fidelity of PC-based flight control devices. Their study measured two groups using differing PC-based flight controls, and a control group. Participants were briefed on basic flight maneuvers and then provided training and practice using the PC-based flight simulators. Later all three groups were evaluated in a real aircraft to measure their performance on flight maneuvers and to measure their workload levels. They found that there was a significant benefit in using the simulators for introductory flight training. However this was due mainly to the reduction in cognitive workload in the air – afforded by the earlier training and practice that the students had completed in the simulator. There was no significant evidence of positive transfer of the psychomotor use of the flight controls, although the group using higher-fidelity controls did perform better in some tasks.

In a similar vein, Koonce & Bramble (1998, p. 287) emphasise that effective transfer of training from a simulator to an aircraft is more to do with the underlying cognitive principles involved, rather than the physical and psychomotor elements.

A study by Johnson & Stewart (2005) examined the effects of PCATDs on various aspects of primary helicopter pilot training – including the use of flight controls. The study analysed feedback from participants after performing specific training tasks in a simulator. The most common difficulty reported by students was a lack of field of view, lack of depth perception, and difficulties maintaining a hover maneuver (p. 301). For these reasons participants generally supported the simulator as a useful tool for instrument training, but of very little use for primary flight maneuvers. In fact, there was evidence of potential negative transfer of flight control manipulation from the simulator to a real helicopter.

However, Embry-Riddle University have found that the use of more complex simulators (FTDs) with higher fidelity visual displays and aircraft flight modeling did show a positive transfer of training for ab initio pilots undergoing visual flight training (Macchiarella & Brady 2006). FTDs are generally of higher fidelity and sophistication than desktop PCATDs. The fidelity of contemporary PCATD software has improved significantly in recent years, however the extent to which PCATDs can be used for visual flight training is not evident at this point-in-time. The concerns of flight instructors remain, despite the improvements in PCATD simulation software.

Given these findings there appears to be no evidence that PCATDs are effective in the transfer of training for the use of flight controls. There is some evidence of negative transfer and general concern regarding this amongst flight instructors. There is limited evidence that simulators can be used for visual flight training (which encompasses basic flight controls and maneuvers) however this was derived from experiments conducted in higher-fidelity FTDs. It is reasonable to conclude then that the relatively low fidelity of PCATD flight controls and flight modeling (Williams 2006, p. 11) means that they are not recommended for training in flight control handling. PCATDs may well be useful for rudimentary introductory lessons or as a classroom demonstration device (Williams 2006) but this would appear to be their limit in regards to the teaching of flight control handling

5.5 The effects of realism and fidelity levels

In relation to flight control fidelity (above) Williams goes on to say (2006, p. 29):

> Much of this disappointment with virtual flying stems from confusion between the "flight model" and the subjective "feel" of how a simulated aircraft responds to the controls. This issue is compounded by a lack of sensory input and the limited view typical of PC-based flying.

There is obviously a significant differential in fidelity and level of realism between PCATDs, most FTDs, and fully-fledged professional flight simulators. While the fidelity of PCATDs is increasing steadily, there remains a finite difference between a desktop-oriented device and a specialised, highly immersive cockpit simulator.

This 'disappointment' is reflected by (Collins 2000) who observed some negative learning experiences within a university program that relied heavily on PCATDs during early classes. Computer performance did not always match the performance of the actual aircraft, and this was especially evident during slow flight and stall maneuvers. He also describes problems with the limited visual displays which encouraged poor visual scanning habits.

Williams (2006, p. 31) also describes limitations with kinesthetic inputs and field of view. There are cues of movement and inertia that are perceived readily by trainee pilots in an aircraft through multiple senses, which are only perceived (in part) in a PCATD by simulated visual cues that can be easily missed.

These issues would seem to limit the effectiveness and validity of PCATDs in many aspects of visual flight training – especially more advanced maneuvers such as aircraft stall and spin training where a high level of fidelity and flight modeling is required (Williams 2006, p. 33)

It may seem logical then to conclude that if the fidelity / realism of PCATDs are increased significantly that this may bring about a corresponding improvement in training effectiveness and transfer. However Beckman (1998, p. 11) cautions that 'If high fidelity does not lead to high transfer of training, the concern over simulator fidelity is overstated.' He points out that high-fidelity devices may actually detract from training effectiveness for new / trainee pilots as they become overwhelmed by the complex learning environment (p. 13).

Fletcher and Tobias (2006, p. 18) made a similar finding in their review:

> It is important to note that positive transfer is facilitated not by overlap in the superficial appearance of games/simulations and external tasks, but by similarity in the cognitive, and perhaps psychomotor, processes engaged in both contexts.

If the fixation with increasing fidelity that seems to pervade the commercial flight simulation field also pervades the PCATD field, the benefits of this increase versus the costs are therefore questionable, and, possibly detrimental to the actual potential of PCATDS as learning environments.

Alexander et al. (2005, p. 5) call for a balanced approach with compromises between fidelity, costs and training effectiveness – noting the high cost of providing high-level-fidelity simulations that do not guarantee a corresponding increase in training effectiveness.

5.6 Task immediacy and complexity

Together with the issues regarding basic flight control training (discussed earlier), there are further issues regarding the use of PCATDs in curriculum for trainee pilots.

Taylor et al. (1999) studied two groups of students by comparing the time to complete various criteria during training in an airplane. One group had received prior training in the criterion in a PCATD, the other group did not. The study showed a clear transfer of training effectiveness for new tasks introduced to the students, but this was less so for tasks already learned.

In another study involving novice pilots, Roessingh (2005, p. 67) hyopthesised that 'complex flying skills, learned on the ground, transfer to the aircraft'. Three groups of novice pilots were trained in various aerobatic maneuvers, preceded by ground briefings. Two experimental groups also received prior instruction in a PCATD before each flight. Each student's performance was analyzed to determine their level of skill on the maneuvers. A unique element of this study was that each flight was analyzed using real-time data recorded in the aircraft – enhancing overall validity and adding considerable depth to the conclusions. Results indicated that there was neither a negative nor positive transfer of manual flying skills from the PCATD to the aircraft. This is a significant variance from other studies that are based primarily on subjective scores provided by instructors or observers. One positive discovered, however, was that students who had received PCATD training/review tended to take less time to attain a skill level than those in the control group.

Both of these studies, which are relatively comprehensive, indicate that PCATDs are more effective in the introduction of new skills and this can translate into less time taken to attain a skill.

5.7 Primacy and habit formation

Primacy is another issue for early flight training noted in the literature. Primacy is a fundamental principle of learning and memory, documented in the fields of education / training and psychology. Briefly, the principle is that whatever is learned first is often learned / remembered most effectively (Corsini 1999). The further implication of this principle is that whatever is learned first is also the most difficult to relearn, or to reverse.

For student pilots who use PCATDs many aspects of flying an aircraft are first learned on the PC-based simulator. For those who undertake self-directed learning with PCATDs prior to formal training, they have the added issue of learning without a professional instructor present, and without the benefit of flying a real aircraft as part of their learning. Given the concerns raised in regards to flight controls, aircraft handling and visual flight training (Dennis & Harris 1998; Johnson & Stewart 2005); PCATDs may therefore be detrimental in this context - in that fundamental and critical psychomotor skills may need to be relearned.

As an illustration, Birckbichier (2002, p. 2) describes this issue and its negative effects in practice:

> One CFI described a student who had logged 300 hours of Microsoft Flight Simulator time and yet couldn't come close to landing an actual airplane. "The technique he used to land a virtual airplane was different than that required for a successful landing in an actual airplane," he said. "This resulted in additional training to unlearn the bad habits acquired from the simulator."

Williams (2006, pp. 27-28) discusses this issue in the context of negative transfer and the formation of bad habits. His experience in the aviation industry conveys a general concern among flight instructors about some of the bad habits which can form with the use of PCATDs. These observed habits are generally in the areas of incorrect flight control inputs, misunderstandings about systems and procedures, and gaps in the knowledge, understanding and performance of basic tasks.

A common example of poor habit formation is instrument panel fixation (Williams 2006, p. 40). Birckbichier (2002) concurs that student pilots who use PCATDs for self-directed learning tend to fixate on the instruments and not look outside the aircraft – requiring more training to relearn correct visual flight scanning and situational awareness.

However, Williams (2006, p. 27) goes on to point out that:

> …fledgling virtual aviators are also far ahead of those with no prior aviation experience… [and] … usually adjust rapidly to real-world flying and make good progress in their training.

5.8 Issues in advanced pilot training

Studies and literature in advanced aspects of pilot training generally focus on aspects of instrument flying skill. Instrument flying, or flying under Instrument Flight Rules (IFR), involves various flight maneuvers and approaches conducted without reference to the ground or horizon, but to aircraft flight and navigation instruments.

In their study of instrument rated pilots Talleur et al. (2003) found that PCATDs are effective for maintaining instrument currency, and can also be effective in enhancing proficiency. The experiment included groups of pilots using PCATDs and FTDs for training over a 6 month period and found that those using PCATDs performed as well as those using the more complex FTDs.

Taylor et al. (1999) also found that PCATDs were an effective tool for the review of previous instrument flying tasks, however they were only effective when significant time had elapsed between the practice of those tasks.

This is further supported by McDermott's study (2006) where instrument rated pilots reported that their skills improved with practice on the simulator and they believed this would transfer positively to the real aircraft. Their comments were validated in some respects by the data from the study which demonstrated a significant increase in proficiency of instrument flying tasks after using a PCATD.

And in a later study Taylor et al. (2003a) studied incremental transfer of training effectiveness of PCATDs by examining the time taken to complete basic and instrument-based tasks and lessons. In support of their earlier studies, a general transfer-of-effectiveness was found across the tasks. However analysis of incremental transfer revealed that the most efficient and effective total time spent in the PCATD was 5 hours, after which effectiveness reduced. This validates Roscoe's theory (1971) of diminishing returns for effectiveness and the need to identify a specific point in a training program that this occurs.

Emanuel's thesis (1997) involved a comprehensive study of the formal introduction of PCATDs into an existing instrument training curriculum. The progress of students was measured from two groups – the first of which had access to PCATDs as part of their training, and a second control group which used the traditional training curriculum (with no PCATD access). TER and TR were measured, along with various affective variables such as student and instructor attitudes and expectations. Key findings were that there were clearly some aspects of the curriculum that showed positive transfer effectiveness from the PCATD, and some which clearly did not. A further conclusion was that the PCATD had a positive effect where it was used to support introductory tasks at any point in the curriculum sequence. This further supports the assertion that the lack of high fidelity of PCATDs creates a diminishing return of effectiveness as the complexity of training tasks increases (Beckman 1998).

A theme which emerges from these studies is that PCATDs seem better suited to introductory tasks and skills and less suited to more complex tasks. These limitations may be governed by the reduced fidelity/realism of PCATDs (as discussed earlier) in that there is a point in time where a PCATD begins to provide less effective training transfer for a specific task, with a given level of complexity.

5.9 Ongoing pilot proficiency and practice

The low-cost and ease-of-access of PCATDs provides a useful platform for the practice of skills, procedures and maneuvers (AOPA 1998; Williams 2006).

McDermott's (2006, p. 64) study on instrument approach skills reports that 87% of participants within the study credited their skill improvement (which was to a medium or significant degree) to the practice they had undertaken on a PCATD before they were tested..

Frisch, in Collins (2000), is unwavering in his support of the use of PCATDs to support pilots in remaining current and proficient after training has been completed:

> For the pilot who has been conditioned and understands all of the situations affecting the flight, there's no question in my mind that a pilot who [practices using simulation software] is going to remain more proficient than a pilot who doesn't. Such practice, properly done, particularly helps to maintain the pilot's instrument scan….

Taylor's et al. (2003b) tests of instrument currency examined the relative effects of recent experience in a PCATD, a FTD, an airplane, or no recent experience at all (over a 6 month period). From the pre and post proficiency checks it was clear that recency gained from practice in a simulator was valuable, and, on a par with recent experience in an airplane. Of further interest was the finding that the performance of the group using the PCATD was statistically indistinguishable from that of the group using the FTD (p. 16). From these findings the authors recommended to the Federal Aviation Administration (FAA) that PCATDs be permitted for use to meet recency of experience requirements for instrument ratings (p. 15).

Similarly, Beckman's (1998) thesis investigated the effectiveness of PCATDs for instrument training in comparison with FTDs. His thesis was (in part) that PCATDs could present significant time and cost savings in comparison with the more costly and complex FTDs (p. 3). The experiment was constructed on a null hypothesis that there would be no significant difference in results between the two devices. Two groups of participants were involved – the first were trained on a PCATD, and the second on a FTD, before participants demonstrated their proficiency in the air. Each student was scored on the accuracy of their instrument flight maneuvers (holding patterns). Beckman's analysis found that the null hypothesis was proved, that is, there is no significant difference in the transfer of training between PCATDs and FTDs. The scope of these findings is limited however due to the small sample size, and the narrow specificity of the tasks analysed in the study.

A more comprehensive study with a similar null hypothesis was conducted by McDermott (2005). This included attention to relevant independent and dependent variables, a control group, and the use pre and post tests. The tests focused on instrument landing system (ILS) proficiency as a subset of instrument proficiency. As in Beckman (1998), the null hypotheses was also supported – there was no statistical difference shown between the performance of pilots using PCATDs for practice versus those using FTDs. The PCATD was also found to be as effective as the FTD in this context. Feedback from participants indicated strong support for the use of PCATDs both for training and as effective tools for ongoing proficiency (p. 55). Participants generally supported the notion that PCATDs improved their skills and this was transferable to their piloting in a real aircraft. In fact 95% of participants recommended that the FAA should approve PCATDs for use in instrument proficiency requirements.

There appears, therefore, to be a strong case in the literature for the use of PCATDs to support pilot proficiency. However it is unclear at this point if these cases and subsequent recommendations put to the FAA will result in regulatory change to allow increased use of PCATDs in this regard (McDermott 2005).

Looking beyond the specific procedural and psychomotor skills of instrument flying discussed thus far, Brannick, Prince and Salas (2005) focused their experiments in the behavioral realm – that of Crew Resource Management (CRM), which in simple terms is about teamwork in the cockpit. In the study a control group received typical CRM training while an experimental group received training on CRM and flight simulation software. Participants teams were observed after training during two specific in-flight scenarios in a high-fidelity flight simulator. The study found a '…quasi-transfer of CRM skills from a PC-based system to a high-fidelity simulator' (p. 185). There were apparent positive effects on crew behaviour without other indiscriminate effects on piloting skills and procedures. The authors assert that PC-based training should be further integrated into behavioral-oriented training in aviation, and that there is a cost-saving with reduced time in high-fidelity simulators for this type of training.

Section 6 Consideration of learning issues

The use of PCATDs in aviation training is diverse with significant variation between the way individual institutions, and individual instructors, use PCATDs to support training (if at all). Given this, and the training issues discussed in section five, this section will examine relevant educational issues with the aim of informing a basis for practice in this context.

6.1 Simulation and educational design

Within the aviation industry there is evidence of concern regarding the use of simulators and their role in training programs. Salas, Bowers & Rhodenizer (1998, p. 198) assert that in the aviation industry the practices of simulation and training have merged into a single, indistinguishable practice. This is a significant educational concern as it involves a number of invalid assumptions, and, hinders the incorporation of scientific and educational advances to improve aviation training in general. The authors detail these assumptions as:

1. An over-reliance on simulation - based on an ignorance of learning theory, and a primary goal of cost-savings
2. That higher fidelity simulation will increase training effectiveness – an assumption that is not supported in the literature.
3. An unchallenged belief amongst aviators and instructors that simulation is inherently good and should therefore be maintained or increased. This is based on questionable evaluation techniques that are sometimes biased and often subjective.

Salas, Bowers & Rhodenizer (1998, p. 205) go on to recommend that the aviation training industry should undertake significant change in regards to these assumptions (above), and in particular should shift in emphasis from a focus on technical devices to a focus on learners, and should incorporate behavioral and educational experts at the design level. There seems little evidence in the literature that this debate, and these recommendations, are actually occurring within the aviation industry. For example Caudrey (2004) poses the question 'Can simulators do everything?" and proceeds to explain that, while the answer to this is "no", there are a range of technical and fidelity improvements that can improve simulator training still further. He emphasises that simulation should be driven by learning needs but his emphasis is still squarely on technical improvement rather than educational design improvement. As Williams (2006, p. 50) says '… instructors too often focus on what a device can do and not how it can creatively be used.'

In the meantime, the fields of educational design and training have continued to evolve with contemporary practices such as curriculum design that is based on learning needs analysis, learner-centered curriculum, programs that allow for adult learner characteristics, and objective evaluation and continuous improvement practices – to name a few. Yet there is little evidence of this work being considered or integrated into aviation training. Emanuel (1997, p. 3) states

> On the whole, curriculum development in flight training has undergone little scrutiny. Ideally, curriculum, instruction, and assessment should combine in a triad to form the basis of all education …

Juhary (2006) points out that the practice of simulation in learning draws not only on the behavioral theorists such as Skinner and Gagne, but also draws inter-dependently on cognitive and constructivist theories, such as those of Piaget, Vygotsky and Skinner. Similarly, in their meta-review Fletcher & Tobias (2006) conclude that it is the cognitive processes that underlie games and simulations that tend to improve with use, and, tend to induce the most effective transfer-of-training. The cognitive aspects of pilot training are profound, yet it is often described and assessed in terms of pure behavioral competency. Given the evidence in the literature of the importance of the cognitive and principle-based aspects of pilot training (Emanuel 1997; Koonce & Bramble 1998; McDermott 2006) there appears to be a significant disparity here between contemporary educational theory and practices and how simulation in aviation training continues to be practised.

The general lack of educational design and the incorporation of educational theory and practice within the aviation field is therefore a significant issue. In the literature much of this concern is directed toward high-fidelity simulation within airline pilot training programs, however the concern is also relevant to the use of lower-fidelity PCATDs and FTDs. While some aviation training practitioners have begun to make recommendations on the educational design of programs that incorporate PCATDs and FTDs (Williams 2006; Macchiarella & Brady 2006), this does not appear to be prevalent at this time.

In a related discussion of the design of games and simulations for learning, Fletcher & Tobias (2006, p. 19) make a relevant point here. That is, that educational simulation should be designed by multi-disciplinary teams which integrate theory and practice from the domains of instructional design, pedagogy and educational psychology.

6.2 The role of PCATDs in training programs

The appropriate level of PCATD use within training programs, and the appropriate topics for which PCATDs can be used, are further questions derived from the literature.

As stated previously, increased use of PCATDs provides diminishing returns and there is a point where the transfer-of-training effectiveness will become inefficient. (Taylor et al. 1999, p. 332). In their subsequent study on instrument rated pilots Taylor et al. (2003a, p. 4) found that there was no further benefit discernable beyond 5 hours of PCATD use. They also found no support for increasing the amount of PCATD use beyond the 10 hours currently allowed by the FAA - with a relative reduction of training time in an aircraft. The most efficient PCATD time (in total) would naturally vary with each major pilot training scenario. For example - it may significantly vary from 5 hours for the training of novice pilots. The pertinent point here is that the recommended amount of PCATD time for each major grouping of pilot training should be identified and not exceeded. The benefit of this is to ensure peak efficiency of learning time and peak costs savings, with a balanced use of the PCATD and time spent in an aircraft.

This integrated balance of PCATD use is supported in several studies. Dennis & Harris (1998, p. 263) recommend that the use of PCATDs be integrated with in-air training but not as a replacement for it. They suggest that 'The objective of using low-cost simulation in the initial stages of instruction should be to maximise the quality of instructional time in the air'.

This is echoed by Macchiarella & Brady (2006) and Macchiarella, Arban, & Doherty (2006) who demonstrate that FTDs can be used effectively in flight training when the learning topics are purposefully integrated with training in the air. Their call for integration of FTDs within professional training curricula is relevant also to the integration of PCATDs within curricula.

Further to this, several studies recommend that PCATDs are best used in the early phases of training programs. This does not mean however that PCATDs are limited only to the early training of novice pilots - as has already been shown there is significant evidence of effective use of PCATDs in advanced pilot training, especially for instrument flying tasks. Emanuel (1997, p. 67) found PCATDs had proven most effective in '…introductory lessons prior to attempting the maneuver in the actual airplane'. After this, further training in the PCATD had diminishing transfer effectiveness. Taylor et al. (2003a) also found that tasks learned in a PCATD generalised to tasks learned later and this caused a subsequent reduction in training transfer for those later tasks. Williams (2006) makes several recommendations for instructors to use PCATDs as introductory tools to demonstrate specific tasks, or to train on part-tasks, prior to experiencing those tasks in an actual aircraft.

Williams (2006) champions the flexible use of PCATDs within training programs. He argues that it is a mistake to focus on a PCATD as a fully-fledged flight training device and warns that they should not be used to teach students as if they were in a real aircraft. This concurs with the earlier discussion on the limits of fidelity and how this reflects on basic flight training. He argues that the PCATD should be used instead as an interactive, multi-purpose tool and suggests the following types of use:

- A platform for repeated practice.
- For pre-flight briefing preparation.
- For post-flight debriefing and further practice.
- For self-instruction - under instructor supervision.
- For demonstration of tasks, procedures and devices that can be done just as effectively outside of a cockpit.
- A multimedia demonstration and scenario-based learning tool for classes and large groups.

Similarly, Homan (1998) discusses the potential of personal computers in the role of PCATDs and as multimedia platforms. He stresses the importance of integration of PCATDS and PCs in formal aviation training programs, and, emphasises the role of the flight instructor as key during all phases of training.

The role of the flight instructor is an important point in this context. Williams (2006, pp. 27-28) concurs with Homan (above) in his discussion on trainee pilots who have previously used PCATDs for self-directed learning without the supervision of a flight instructor. These pilots tend to exhibit the negative habits that were outlined earlier in section five. Hays (2005) recommends that instructors should be positively involved in the selection and integration of simulation tools into training programs – including the provision of briefing and debriefing on specific tasks. He also recommended that self-directed learning tools should include instructor-like features where possible to support learners.

6.3 Simulation, gaming and learning

As discussed in section four, PC-based flight simulators are used in diverse roles – from pure gaming/entertainment experiences through to advanced flight training tasks. Working definitions of games versus simulations is another major topic and beyond the scope of this paper. But rather than view the gaming and high-end simulation applications as dichotomies, it is perhaps more useful to view the merger of gaming and learning as interdependent variables on a continuum.

Prensky (2001, p. 4) states that 'By marrying the engagement of games and entertainment with the content of learning and training, is it possible to fundamentally improve the nature of education and training?'. There is considerable literature that generally supports the affirmative position in relation to Prensky's question, however, an in-depth discussion of the literature is beyond this review. However, Hay's (2005) recommendation that we should not generalise the effectiveness of one game/simulation to other contexts, and that the literature is somewhat fragmented and has methodological concerns, is worthy of note here.

In recent years there has been considerable growth of interactive gaming for entertainment and a corresponding growth in the use of gaming to support learning in education, commercial and military contexts (de Freitas 2006; Fletcher & Tobias 2006; Ford, Barlow & Lewis 2003).

In general there are calls in the literature for simulation designs to draw further on educational principles and focus on defined learning outcomes (Alexander et al. 2005; Fletcher & Tobias 2006; Hays 2005; Salas, Bowers & Rhodenizer 1998), and for more rigorous evaluation frameworks which are seen as vital to the further development of simulators for learning (O'Neil, Wainess & Baker 2005; Salas, Bowers & Rhodenizer 1998).

A significant genre within this field is 'Massive multiplayer online gaming' (MMOG) where users connect together and interact in a game or simulation in real-time. MMOGs have grown exponentially with the Internet (Bonk & Dennen 2005). Ford, Barlow & Lewis (2003, p. 4) point out that PC-based simulators have considerably more potential in this context than higher-fidelity commercial flight simulators in that they are far easier to set up for this purpose. Indeed the growth of aviation MMOGs - such as the VATSIM network - indicate a potential extension of the role of PCATDs for the training of pilots and air-traffic-controllers in a real-time, networked environment. The extent and depth of an interactive aviation environment such as this is beyond the capability and affordability of individual training institutions. For learning, aviation MMOGs can not only increase the level of interactivity, but can also increase levels of immersion and social presence – two factors highlighted by Alexander et al. (2005) as pivotal within effective simulated learning environments. This has impacts for simulation designers and instructors, as highlighted by de Freitas (2006, p. 6):

> Through modifying existing games applications for educational purposes there is great potential for learning with games. This approach may have implications upon instructional / constructional learning design…

de Freitas (2006, p. 7) further concludes that online learning environments and communities have significant potential for extending and deepening learning experiences, and for lessening the lines between informal and institutionalised learning.

6.4 Improving learning with PCATDs

The following issues are not major themes in the literature but are worthy of note in this section. They are relevant to the improvement of learning in this context.

Integration of cognitive principles
As noted earlier, cognitive and behavioral aspects of aviation training/simulation have attracted little attention in the industry. Koonce & Bramble (1998 p. 287) assert that:

> The important factor in the transfer of basic flight skills may lie in the transfer of cognitive principles underlying successful task performance rather than the transfer of proprioceptive cues from physical identical elements from the device to the aircraft itself.

They recommend that part-task training be designed to emphasise and support the underlying cognitive principles on which those tasks depend, and that simulation-based training can play a key role in this respect

Minimising the negative transfer of training

Williams (2006, p. 28) outlines a number of training strategies to minimise the negative transfer of training:

- Identifying the skills and tasks best suited to PCATD training.
- Use the PCATD for its strengths and not its weaknesses (see section 5).
- Use the PCATD to practice increasingly complex conceptual tasks.
- Provide clear distinction between how tasks in a PCATD will differ in the real airplane.

McDermott 2005 (p. 63) also recommends that pilots be introduced to simulators purposefully in order to reduce the cognitive load and anxiety of entering a new learning environment. The role of flight instructors is vital here – as discussed by Hays (2005).

Section 7 Summary and conclusions

PC-based flight simulators have developed into sophisticated software packages that leverage the power of personal computers to a significant level. They provide a low-cost, accessible and flexible platform for entertainment and learning, from the self-directed style of learning undertaken at home by non-licensed-pilots, through to fully integrated task training in commercial pilot training programs.

This review has considered 57 studies, papers, reviews and articles relevant to this topic from 1997 through to 2007. The conclusions made in this review should be read in context with the cautions of Carretta and Dunlap (1998) and McDermott (2005). They indicate that scientific evidence in this field is somewhat limited due to a lack of control groups, variable manipulation, and narrow task / skill foci in studies; and, a lack of documented detail of methodologies and contextual characteristics of training and simulators used in experiments.

With these limitations in mind, there is clear support in the literature for PCATDs as useful and effective tools for learning. The majority of empirical studies and reviews in the field have found positive transfer-of-training from PCATDs to real-life flight-training and flying. This finding extends from the training of novice pilots through to instrument-rated and commercial pilots.

PCATDs are, in educational terms, a superior learning environment to an airplane, there are definitive time and cost-savings to be realised, and they are effective for part-task and procedural training for individuals and groups. They also provide a useful platform for pre-flight preparation, the ongoing practice of skills and procedures, and as multimedia tools for teaching and learning.

Various studies found that PCATDs were more effective at teaching introductory tasks that were sequenced earlier within training programs. They tended to be more effective when those tasks introduced students to underlying cognitive principles that could be applied later in their training.

There are however disadvantages and limitations. The literature indicates that PCATDs are not effective, and possibly detrimental, to early flight training involving the use of flight controls and the performance of basic flight maneuvers. There is a wide gap between the fidelity of high-end simulators and PCATDs, and research indicates that increasing the fidelity of PCATDs is not a viable solution to this issue.

Some of the literature revealed that PCATDs can produce negative learning outcomes and create poor habit formation – especially for self-directed novice pilots. Skills and assumptions must then be relearned, which can mean a corresponding increase in training time and cost.

Given the various advantages, disadvantages, issues and limitations of using PCATDs for aviation training; PCATDs appear to have a significant yet limited role. This role should be both defined and understood if PCATDs are to be used effectively and efficiently. As part of this understanding - the multi-purpose nature of PCATDs as tools for teaching and learning needs to be further embraced. Rather than force students to use PCATDs as if they were real aircraft, instructors and institutions should focus on creative ways to integrate PCATDs into programs, in order to leverage the strengths and potential that PCATDs can provide. In this way PCATDs can be a useful component within holistic learning designs, rather than being viewed as wholesale replacements for or threats to training in an actual aircraft.

Underlying this is a general absence of applied learning theory and practice in the aviation training industry where there is a strong focus and reliance on high-fidelity simulation as “the” answer to training, and a lack of critical evaluation of learning approaches and curricula. Further underlying this is a lack of integrated team development of curricula and simulation environments that leverage critical contributions from the fields of educational design and educational psychology.

There is a positive and active role for PCATDs already established within the aviation industry, but there is considerable potential for more research and greater development in the field. If software producers, aviation educators and flight instructors can work together with the broader educational community then there is further potential for the role of PCATDs to be better defined, and for their role to be more effectively integrated into aviation training curricula throughout the industry.

Section 8 Questions and topics for further research

Throughout this review a number of key themes and questions for further research have emerged:

1. Determination of the underlying cognitive principles that are effectively transferred through the use of PCATDs during training. Explicit knowledge of these principles could aid curriculum designers and flight instructors to more effectively integrate and sequence the use of PCATDs within training programs.
2. More empirical studies are needed which utilise objective and scientifically valid performance measures. Studies of wider scope would also be useful – including broader experimental samples, and, more comprehensive ranges of tasks and skills studied for comparative analysis.
3. Further determination of the factors of PCATD fidelity that increase and decrease transfer of training effectiveness. This information could assist software and hardware designers to focus on specific improvements that will translate into training efficiencies. Research findings could also positively influence regulatory bodies to provide a scientifically grounded and explicit basis for the certification criteria for PCATDs – something which appears to be currently lacking.
4. Research and recommendations for developing a descriptive framework for classifying PCATDs would assist in reducing the current disparities between legislative bodies. An accepted framework could also provide more useful determinations of the appropriate uses of various types of PCATDs, and more appropriate allowances for their use in formal flight training and pilot proficiency. The framework could be extended to include FTDs and high-end simulators.

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Appendix-A Methods used to identify and select literature

The literature search was undertaken between March 2007 and June 2007.

Literature was accessed by searching academic journals, citation indexes, electronic databases, dissertation databases, literature abstracts, internet sites (via Google and Google scholar), and conference papers. Searches were focused within the disciplines of education; gaming and simulation; educational/aviation psychology and aviation training. Requests for literature were made on relevant aviation / simulation internet forums; and by email contact to major simulation training providers and institutions.

Keywords used

The major keywords used for searching the literature base were (including combinations and derivatives of):

- PC-based
- PCATD
- Simulation
- Training
- Aviation
- Pilot
- Flight crew

Review criteria

The literature included:

- is published between 1997 and 2007
- deals specifically (in whole or in part) with PC-based simulation and its applications for training in the aviation industry, or from related education fields where relevant to the review, and/or
- deals with one or more of the research questions posed in section two.

Appendix-B Acknowledgements

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> As an interesting postscript … it is fascinating to note that professional simulators for the world's largest and newest passenger aircraft – the Airbus A380 – now use the windows-based personal computer as its computing platform (Australian Aviation 2007). It is somewhat ironic that the highly advanced A380 simulator and the humble PCATD are now driven by similar personal computers. A case of full circle it would seem.

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