CHAPTER TWO:

LITERATURE STUDY –
THE HUMAN-MACHINE INTERFACE

2.1 INTRODUCTION

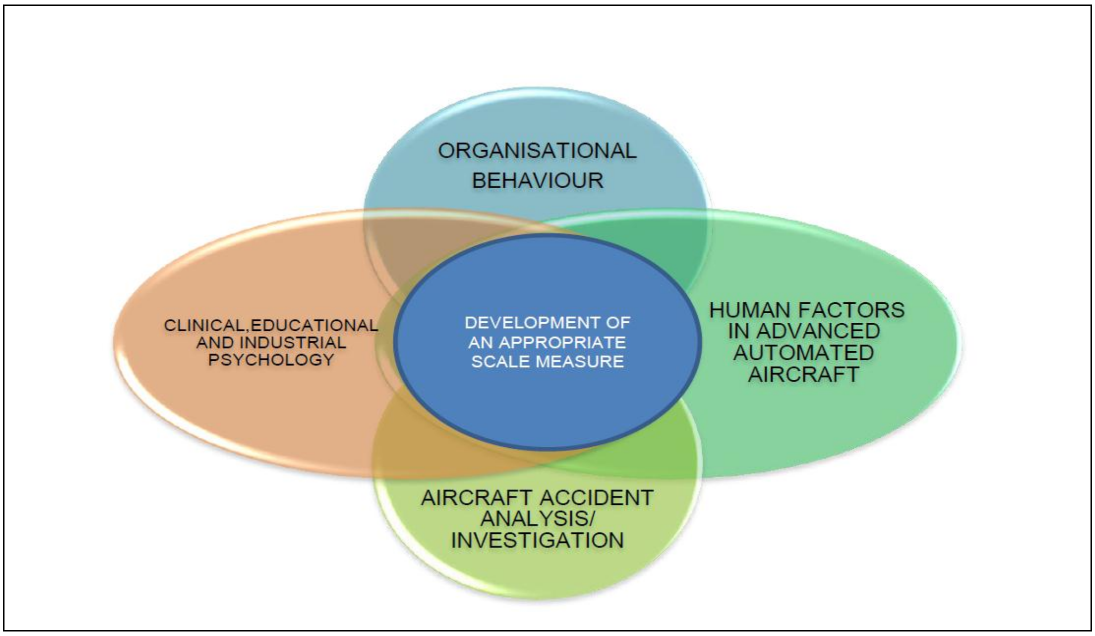
When a study is exploratory in nature, it is crucial to conduct a thorough literature review (Mouton & Marais, 1996). Reviewing the appropriate literature and examining critically, related prior research, can provide a good indication of where the current thesis fits into the context of the present body of knowledge. According to Babbie (2010), an effective review of the literature consists of evaluating selected documents on a given research topic. Human factor research in aviation is a relatively neglected topic when compared to other areas in psychology and organisational behaviour (Dekker & Johansson, 2000). For this reason, much of the literature consulted is at times, as much as two to three decades old. It is therefore intended that the present research study would add new material to the current knowledge deficit, with useful information.

In this chapter, the nature of the interaction between human beings and highly advanced technology in an aviation industry setting is examined; more specifically, the impact of advanced aircraft on human behaviour is discussed. A multi-pronged approach was followed in analysing the evolution of advanced aircraft pilots' current working environment.

Four decades ago, Gordon Moore postulated that the number of transistors on a silicon chip would double every two years (Voller & Agel-Porte, 2002:699) – he claimed that "[a]nother decade is probably straightforward...there is certainly no end to creativity" (Moore, 2003). This prediction has remained true thus far – exponential advances in technology were made possible and the benefits from miniaturised components still continue to proliferate everyday life. The cumulative impact of such advances has unquestionably revolutionised the electronic world. More importantly, especially for the purposes of the current study, it has drastically changed the face of the aviation industry. Commercially available passenger and cargo aircraft employing highly complex computerised automation has become much easier to engineer and manufacture (Australian Transport Safety Bureau, 2007). As in many industries, new technology has always had a significant impact on the lives of those who earn a living from working with it – in the case of the aviation industry, on the attitudes, skills and proficiencies of pilots (Abbott, 2010). As with many technologically advanced products found in today's marketplace, some individuals can easily embrace the necessary learning of the skills required to operate the new product effectively, while others find it less easy to adapt (Naidoo, 2008).

In order to understand the context in which the development training measures are used, it is essential to study the level of aircraft automation. This will enable comment and increase the applicability of the results and recommendations of the study. In this chapter, the advanced and highly automated aircraft is introduced. Thereafter, the chapter critiques the human factor element associated with the technology in order to provide a background for the design of the hypothetical measurement construct intended to meet the research objectives. Figure 1 depicts a contextual framework for the present study, by graphically synthesising the areas covered in the literature review.

Figure 1: Synthesis of the literature study



2.2 CONTEXTUAL DEFINITIONS

Definitions of two key terms used throughout the research are provided in Table 1. The contextual definitions aid in the discussion and literature review which follows and make it easier to grasp the meaning of fundamental aviation automation concepts.

Table 1: Definitions of some key terms

Term	Definition
Advanced Automated Aircraft	According to Risukhin (2001), the advanced automated aspects of aircraft consist of two main components, namely: • the computerised flight deck systems, for example, the flight director/autopilot and the flight management system; and • the computerised airframe and mechanical subsystems, for example, the electronic engine control, propulsion, auto-throttle and auto-thrust functions.
Advanced flight deck or glass cockpit	The glass cockpit is "a system of cathode ray tubes of liquid crystal display flat panels that provide key critical information and control through advanced computers about the status of the aircraft" (Wiener, 1988:10).

2.3 CHARACTERISTICS OF ADVANCED AUTOMATED AIRCRAFT

According to Airbus (2011b:1.22.10), the general philosophy that underpins automating an aircraft is that doing so "reduces cockpit workload, improves efficiency and eliminates many routine operations normally performed by the pilots" in the normal flight envelope. Various scholars (Parasuraman & Byrne, 2002; Sarter & Woods, 1994; Sherman, 1997; Wiener, 1988) provide a similar explanation in terms of defining the automation of aircraft flight decks. In addition, the optimum use of aircraft automation involves the integrated and co-ordinated manipulation of the following basic aircraft components:

- the autopilot;
- the flight director;
- the auto-throttle or auto-thrust systems; and
- the flight management system.

The most advanced aircraft today offer users a fully automated system in terms of both the lateral and vertical profiles (Airbus, 2011a). Ascending levels of computer-based automation provide the flight crew with an ever-increasing number of options and strategies to choose from. The choice of automation options is complex, because it must be accomplished in accordance with the particular task at hand. For instance, tactically complying with air traffic control requirements in the short-term when in close proximity to the airfield, versus, strategically programming the flight management system for long-term navigational requirements so as to safely and efficiently traverse a continent (Parasuraman & Byrne, 2002).

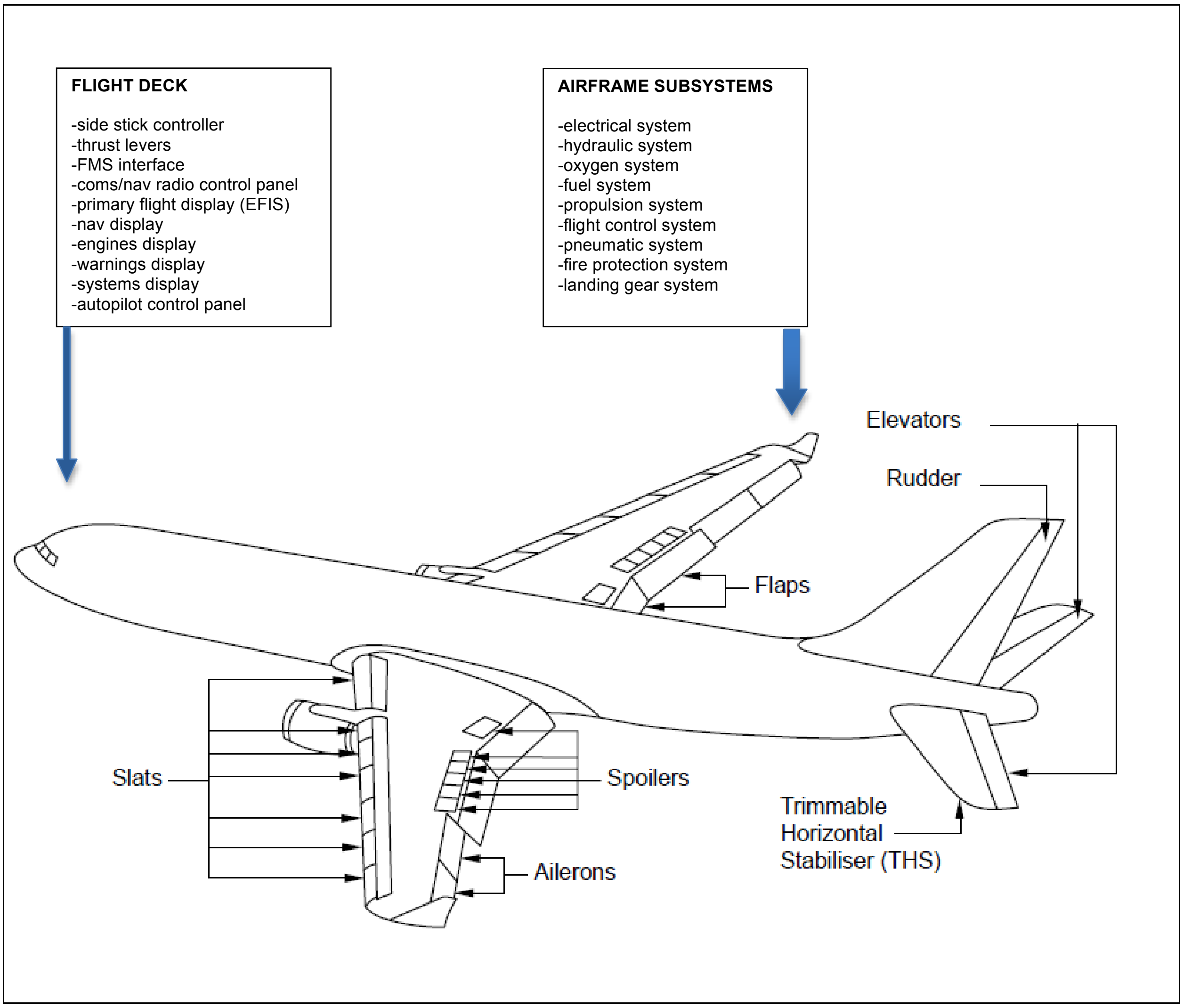
An advanced automated aircraft contains a multitude of primary systems and peripheral subsystems. Flight deck crewmembers that learn to fly such modern aircraft are required by law to understand and comprehend the working details of the aircraft in totality. This includes the on-board computerised flight deck systems and other advanced airframe-related subsystems (South African Civil Aviation Authority, 2011).

When the level of knowledge required by an airline pilot is considered, it is clear that the measurement of any hypothesised construct of airline pilots' perceptions of the climate associated with advanced automated aircraft training at an organisation (airline) is multifaceted and complex. For this study, it was determined that any hypothesising of relevant constructs should encompass an assessment of pilots' perceptions of the climate associated with an entire transition-training course. A full transition-training course consists of understanding two main components of an advanced automated aircraft, namely

- the flight deck systems; and
- the airframe mechanical subsystems.

These two components of the modern aircraft are depicted in Figure 2.

Figure 2: The two main components of an advanced automated aircraft



Source: Adapted from Airbus (2011a) and Risukhin (2001)

For the purposes of this study, advanced automated aircraft refer to the two main components of the machine (computerised flight deck systems and computer-based airframe systems) in combination.

Figure 2 is a model of an Airbus A330 variant, one of the world's most advanced commercial jet aircraft. Some of the fundamental systems of each main aircraft component are shown in the figure, illustrating the complexity of the components. Each subcomponent of the aircraft system requires specific levels of understanding by pilots, so that routine and non-normal operations can be performed safely. A lack of comprehension, or significant knowledge gaps regarding some technical aspects of the aircraft, can result in an unsafe outcome (Ribbens & Mansour, 2003). It is important to note that the evolution of medium to large commercial aircraft over the last fifty years has resulted in pilots' requiring an increased ability to grasp specialised technical concepts. The most important of these are discussed in more detail within the next section.

2.3.1 Computerisation of aircraft systems

Rapid improvements in modern digital electronics have resulted in equally advanced improvements in aircraft design and implementation. Tooley (2007:1) contends that a "modern aircraft simply could not fly without the electronic systems that provide the crew with a means of controlling the aircraft". A technologically advanced commercial jet aircraft is dependent on numerous computer-based systems for an exceedingly broad variety of operations, from flight control and instrumentation, to navigation, communication and electronic engine control. On-board computers sense and indicate the aircraft's trajectory in relation to the earth, the aircraft's heading, altitude and speed. Thousands of invisible sensors in and around the aircraft work in complete harmony with both microscopic and large mechanical devices. Sophisticated computers process a plethora of environmental and internal information, ultimately contributing to a complex and almost "living" entity, which may be, why sometimes, an aircraft appears to have a "mind of its own" (as one survey respondent to this study commented). Without the digital logic provided by highly advanced microprocessors, these types of aircraft would not leave the ground (Tooley, 2007).

Resource limitations and increasing corporate competiveness have ensured that aircraft manufacturers research and build aircraft that take advantage of the benefits of modern micro-processing power. However, the potential for the limitless incorporation of new and sophisticated engineered components in aircraft has raised a number of human-centred concerns amongst experts in the field (Barker, 2011). Critics are concerned with the rate at which technology is being incorporated into the modern flight deck, with the result that there is increased detachment in the human-machine interface (Abbott, 1995; Barker, 2011). Observers have gone so far as to label increased reliance and perhaps over-reliance on aircraft automation and computerisation an *addiction* (Barker, 2011). The current lack of understanding between technology and human behaviour has caused a widening gulf between the opinions of two significant groups of people, namely airline pilots and engineers (Poprawa, 2011). Engineers seek to reduce the need for any human intervention during aircraft operations, whereas pilots seek to gain more control over and flexibility of the aircraft (Sarter & Woods, 1994). The level of computerisation in the modern aircraft is likely to present many challenges and raise debate in both the technical and psychology fields in the foreseeable future. The debate at the future human-human level in aviation, as opposed to the human-machine level of interaction, may prove to be an interesting research topic for further research, however, falls beyond the scope of the current topic.

2.3.2 The dominance of aircraft technology

An analysis of the literature shows that there is some consistency in the various attempts to formulate what constitutes advanced flight deck automation. In most instances, authors share the notion that flight deck automation involves a gradual handing-over of power from the human operator to the computer system (Parasuraman & Byrne 2002; Sarter & Woods, 1994; Sherman, 1997; Wiener, 1988). Increased use of computer processing power in aircraft has given rise to the term "glass cockpits" (Taylor & Emanuel, 2000:18). Table 2 compares the various convergent definitions found in the literature. A number of concerns have been raised by human behaviour experts, regarding pilots' control and management of advanced aircraft and the transition required to adapt to new aircraft technology (Barker, 2011; Lyall & Funk, 1998; Sarter & Woods, 1994). By altering the roles of the operator and the machine, advanced automation has increased efficiency, whilst simultaneously extending the available human capability (Schutte, 1998). Much empirical evidence provided by scholars investigating this area began contradicting the utopian promise that increasing flight deck automation increases safety linearly (Parasuraman & Riley, 1997; Rigner & Dekker, 2000; Sarter, 1996). The new responsibilities left to the human operator have resulted in new mistakes, errors or omissions (Lowy, 2009). A paradoxical decrease in situational awareness, increased mental workload, poorer efficiency in systems monitoring and a degraded ability to intervene during an automation failure are some of the concerns that have been cited. Interestingly, all of the major concerns being raised in the literature with regards to advanced aircraft, link the human being directly. The fact that there may be a distinct lack of understanding or comprehension of critical (more complex) technical topics by advanced automated aircraft pilots is a reason for the past and present concerns (Lyall & Funk, 1998; Poprawa, 2011). Some studies have noted a negative correlation between factors such as understanding and comprehension, and pilots' perceptions of advanced flight deck automation (Naidoo, 2008). In other words, the increasing dominance of complex systems may result in a reduced ability to understand these aircraft. Problems with understanding technology or pilots' lack of actually comprehending aircraft system complexity can be linked to the effectiveness or ineffectiveness of organisational training efforts (Moore, Po, Lehrer & Telfer, 2001). Researching the phenomena associated with such organisational efforts also provides a reason for further perception studies involving advanced aircraft.

Table 2: Definitions of advanced flight deck automation

Source	Definition of advanced flight deck automation
Wiener (1988:436)	Flight deck automation is "when some tasks or portions of tasks performed by the human crew can be assigned, by choice of the crew to machinery". Cockpit automation is also "regarded as computational support allowing some procedures to be omitted by the crew".
Sarter and Woods (1994:5)	Flight deck automation is "the allocation of functions to machines that would otherwise be allocated to humans".
Sherman (1997:2)	Flight deck automation is "the replacement of a human function, either manual or cognitive, with a machine function".
Parasuraman and Byrne (2002:315)	Flight deck automation is "the gradual and increasing replacement by machines and computers of functions once carried out by flight deck crew".

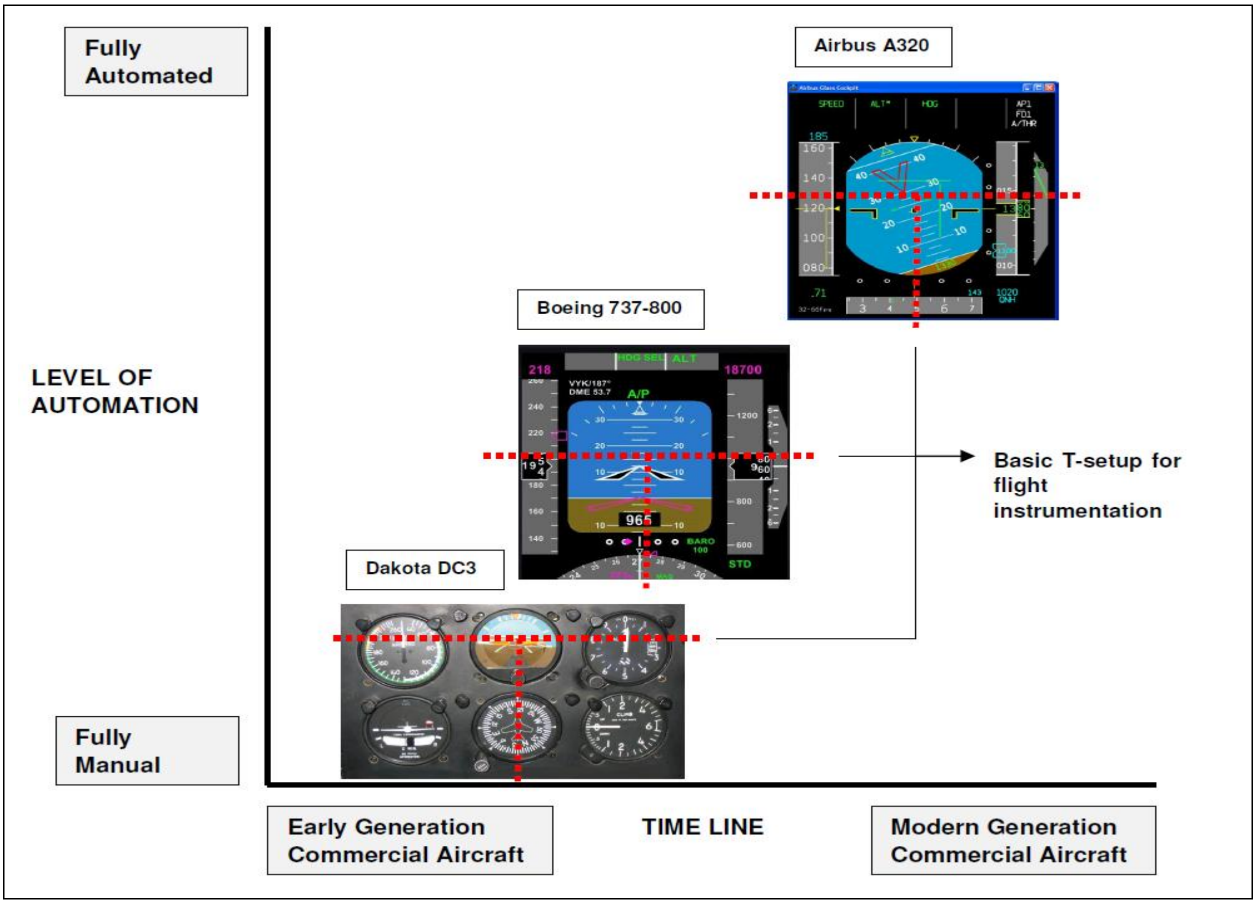
2.3.3 The advanced flight deck

Advances in technology have changed the appearance of flight decks substantially. A core difference between an analogue flight deck and a modern digital or glass flight deck is that in the glass set-up there is extensive use of electronically generated graphic displays (Airbus, 2011b). These displays are also coupled with underlying computer sensors, electronic circuitry and software. This remarkable evolution of the flight deck (from analogue instrumentation to digital instrumentation) is the most noticeable and tangible difference between older aircraft and the modern generation of aircraft (Risukhin, 2001). Because the most significant differences between the various periods of aircraft design can be found in the flight deck itself, most of the subsequent discussion relates to these differences. In addition, a significant proportion of automation issues and problems in the human-machine interface occur in relation to flight deck systems rather than in relation to airframe sub-systems (Parasuraman & Byrne, 2002).

The digitised flight deck system effectively and efficiently replaced the earlier analogue system in commercial aircraft approximately fifteen years ago (Ribbens & Mansour, 2003). The quantum leap in aircraft technology since the inception of flight has resulted in a series of revolutionary changes in the basic flight deck layout. The most obvious changes in aircraft design are noticed in the cockpit – or more correctly, the flight deck (when one refers to a commercial transport airliner). These are overt design changes, which give rise to the *glass* concept, whereas the peripheral mechanical subsystems of the advanced aircraft airframe may be considered latent changes in design. However, the latest generation of commercial jet aircraft, such as Boeing’s 787 variants have seen a radical airframe update. These aircraft now boast noticeable wing and fuselage design changes, which are claimed to make the aircraft far more fuel-efficient and environmentally friendly (Boeing, 2009). Figure 3 depicts the advances, which occurred in flight deck instrumentation design during this transition (the timeline on the horizontal axis shows the independent variable, with the level of automation on the vertical axis as the dependent variable).

In order to maintain the correct and efficient scan of primary flight instruments, the initial design of the instrument display in an aircraft features a T format (Abbott, 2010). In this format, critical indicators such as the aircraft's lateral speed, trajectory and vertical speed are found at the top, and directional indicators such as the compass and turn-and-slip indicator are positioned below the T-bar. Although the basic T set-up of primary flight instruments has remained unchanged for some time, Figure 3 clearly depicts the significant ergonomic and aesthetic evolution in the primary flight instrumentation of the glass flight deck. The use of digital displays provides pilots with a tighter clustering of important flight information, resulting in improved situational awareness. Engineers are likely to continue to use the T set-up for displaying flight information to pilots, because "maintaining the relevant positions of the instruments has been important in allowing pilots to adapt from one aircraft type to another" (Tooley, 2007:11).

Figure 3: Evolution in primary flight instrumentation



Source: Adapted from Lyall and Funk (1998), Ribbens and Mansour (2003) and Tooley (2007)

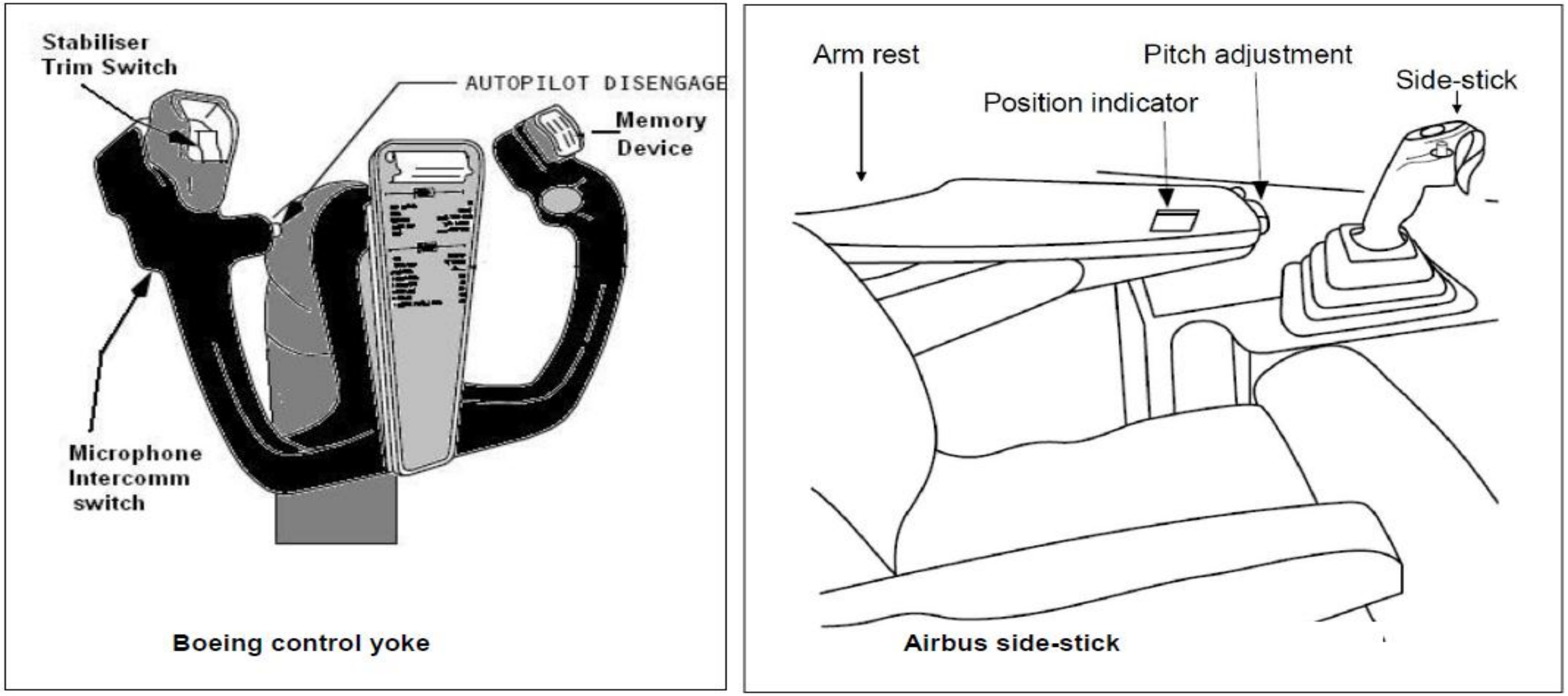
Other design changes in the modern flight deck have occurred in the way pilots manipulate the aircraft flight control surfaces. A critical difference between the design philosophies adopted by the two largest commercial aircraft manufacturers, Airbus and Boeing; is that Boeing continues to use a central control column as a means of manual flight control (Figure 4). By contrast, present-day Airbus commercial jet aircraft use an extremely sophisticated piece of technology, namely the side-stick, for manual control of the aircraft (Airbus, 2011a). The logic incorporated in the side-stick is highly complex, but it has proved to be an invaluable tool that has improved both ergonomic efficiency and aircraft safety characteristics. Nonetheless, experts in the field tend to disagree on which of the two systems is safer or more effective (Barker, 2011; Bent, 1996; Helmreich, 1987).

In normal flight, Boeing provides the pilot with comparatively more manual intervention from the central control column, while the Airbus side-stick system remains semi-automatic (Figure 4), and never allows for full manual control by the pilot (full manual control can only be achieved through the horizontal stabiliser for pitch, and rudder control for yaw, when in direct law, that is, after the failure of all the flight control computers, which is highly unlikely).

Boeing continues their philosophy of retaining a central control yoke in their most advanced aircraft to date, the B787, although the central control column is now based completely on fly-by-wire technology (advanced computerised automation, therefore there is no mechanical link between the control yoke and the aircraft flight control surfaces. Also see Figure 7).

The Boeing manufacturer premise is that commonality is sustained between the company’s family of 777s and 787s, allowing for quicker conversion (transition) type training by maintaining the more conventional control column design. By contrast, Airbus Industries have argued that the removal of the central column means that a pilot’s view of the primary instrumentation is no longer restricted, thereby providing a superior ergonomic state (Hradecky, 2011).

Figure 4: Comparison of specific flight control mechanisms

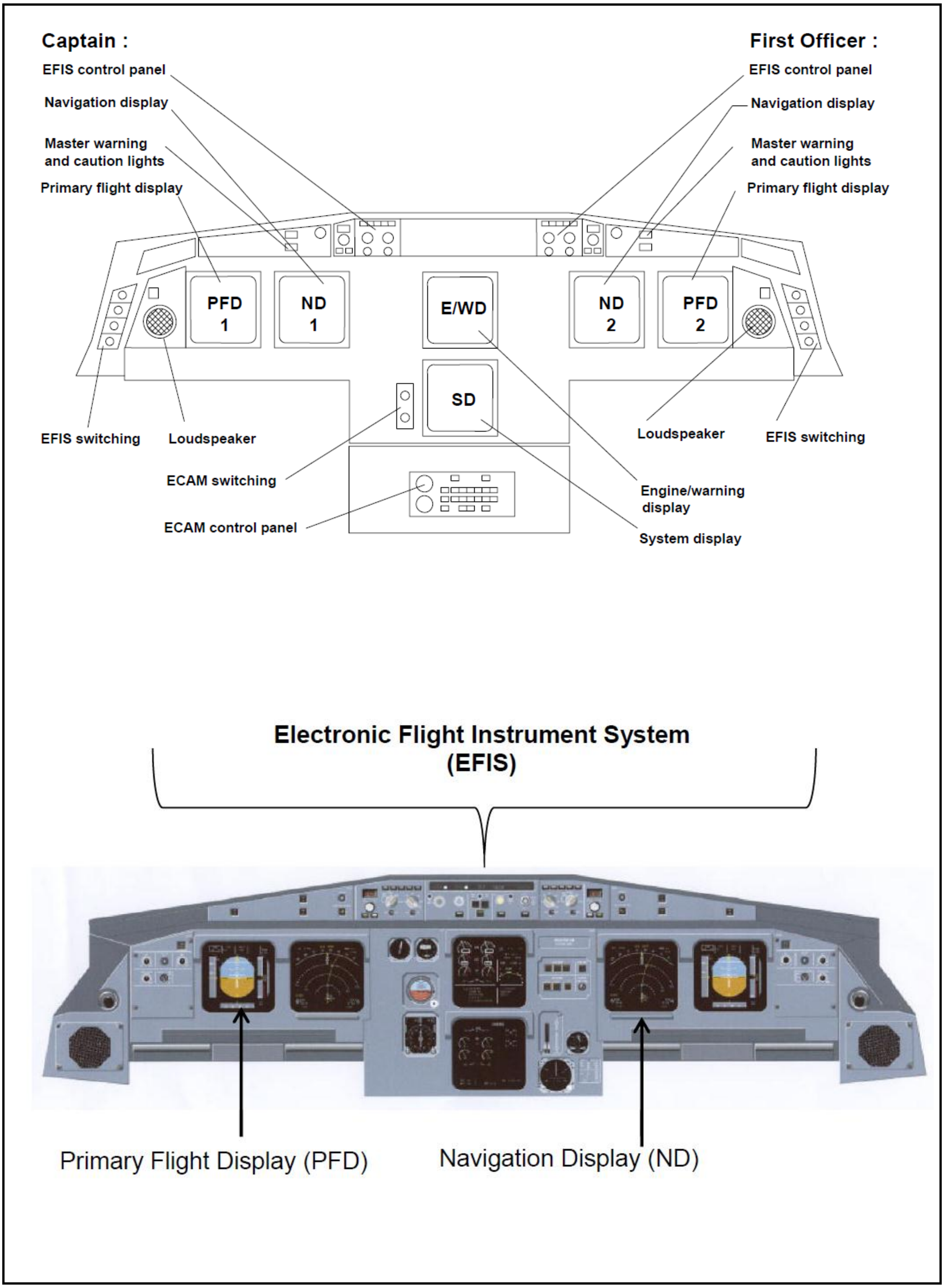


Boeing control yoke

Airbus side-stick

Sources: Adapted from Airbus (2011a) and Boeing (2010)

Figure 5: Advanced flight deck instrumentation console (Airbus A320 example)



Source: Adapted from Airbus (2011a)

Figure 5 illustrates the advanced flight deck instrumentation console housing the *glass* display system. In an advanced aircraft such as the Airbus A320, important displays for aircraft control are integrated within the EFIS (Electronic Flight Information Systems), while engine parameters, cautions, warnings and emergency procedures are integrated within the ECAM (Electronic Centralised Aircraft Monitoring) system, which was once the domain of a separate crewmember, namely, the flight engineer. Such a set-up has made it possible to operate even the largest passenger commercial aircraft with only two crewmembers. Furthermore, the overall system is designed in such a manner that appropriate information is presented in a timely and arguably more effective manner to the pilots. The principle of the display design is that it prevents an overload of unnecessary incoming information, therefore making it possible to operate the aircraft with less crewmembers then ever before (Parasuraman & Byrne, 2002).

The advanced flight deck layout also illustrates how designers have kept the most important flight information displays in a familiar configuration (see also Figure 3), allowing pilots to adapt more easily when switching to different models (Parasuraman & Byrne, 2002). This set-up attempts to harness ergonomics in an effort to reduce human-factor related problems and to improve safety measures in a technologically advanced cockpit (Sarter & Woods, 1994).

In addition to the difference in cockpit or flight deck setup, the response of the aircraft's actual control surface deflections after a pilot input, is considered artificial in a modern fly-by-wire aircraft (Hradecky, 2011). According to Dole (1989), the basic control of an aircraft (be it conventional or fly-by-wire) is a product of aircraft pitch (rotation about the lateral axis) and roll (rotation about the longitudinal axis). Some authors then propose that in a conventional aircraft, the pilot has a *sense* of the aircraft from a direct *feel* of control surface deflection, whereas; in the more modern fly-by-wire aircraft this *feel* is artificially generated by computer algorithms to provide feedback to the pilot depending on the current phase of flight (Risukhin, 2001:81-83) (discussed further in section 2.3.4). A comparison of the conventional and the fly-by-wire aircraft (in this case an Airbus A320/A330/A340) handling characteristics are best tabulated in terms of pitch and roll (see Table 3).

Table 3: Conventional and fly-by-wire aircraft control comparison

Pitch	Conventional flight controls	Fly-by-wire flight controls
Pitch Rate	• Pitch rate will vary in terms of control surface displacement and airspeed. • Aircraft pitch is unaffected by loss of airspeed information.	• Pitch rate is commanded by the equivalent in G-loading. • Pitch rate is unaffected by loss of airspeed information.
Aircraft response	• Aircraft response differs at varying airspeed. • Response is unaffected by loss of airspeed information.	• Aircraft response is the same at all airspeeds. • Response is unaffected by the loss of airspeed information.
Aircraft trim	• Trim is manual, and becomes more sensitive with an increase in airspeed. • Trimming is unaffected by loss of airspeed information.	• Aircraft trim is completely automatic. • Trim is unaffected by the loss of airspeed information.
Control column feel	• An artificial feel is introduced to simulate increased stick force at high airspeeds to prevent pilot over-controlling. • Here the basic introduction of an artificial feel can be unrepresentative of actual aircraft speed.	• The control column has the same feel at all speeds. • The feel is unaffected by the loss of airspeed information.
Aircraft envelope protection	• No flight envelope protection. • Unaffected by the loss of airspeed information.	• Full flight envelope protection is provided. • With the loss of airspeed information, the computer can only provide a G-load demand protection.
Roll	Conventional flight controls	Fly-by-wire flight controls
Pitch Rate	• Roll rate will vary in terms of control surface displacement and airspeed. • Aircraft roll is unaffected by loss of airspeed information. However, control limiters may be affected.	• A roll rate is commanded by the pilot's control stick. • Roll rate will vary in terms of airspeed and with control surface displacement, adjusted for aircraft configuration, when airspeed information is lost.
Aircraft response	• Aircraft response differs at varying airspeed. • Response is unaffected by loss of airspeed information.	• Aircraft response is the same at all airspeeds. • Response will vary with a loss of airspeed information depending on actual airspeed and aircraft configuration.
Control column feel	• Aircraft feel is the same at all speed, however, limiters would change the response at high speeds. • Feel is unaffected by the loss of speed information, except for the effect from control surface limiters.	• The control column has the same feel at all speeds. • The feel is unaffected by the loss of airspeed information.
Aircraft envelope protection	• No flight envelope protection. • Unaffected by the loss of airspeed information.	• Full flight envelope protection is provided. • With the loss of airspeed information, the computer cannot provide roll protection.

Source: Adapted from Poprawa (2011)

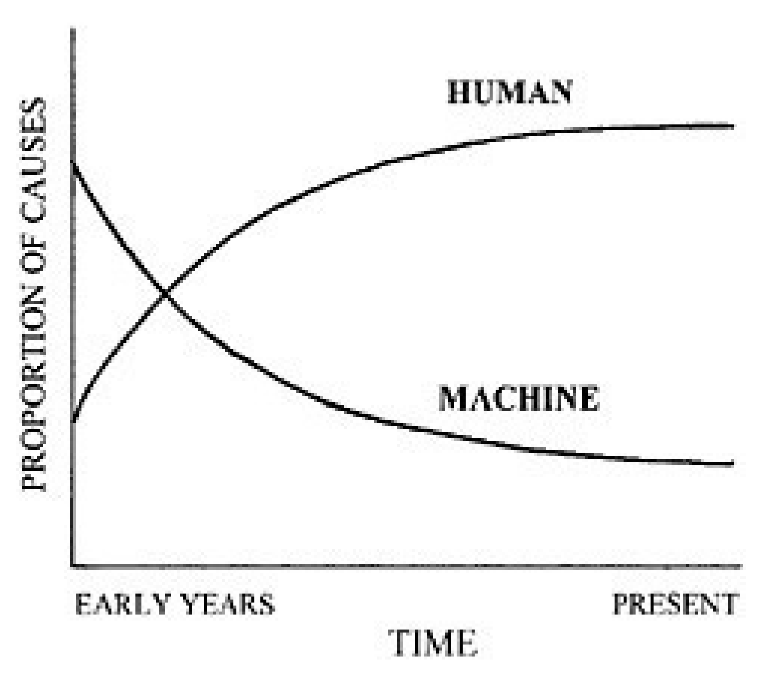
The tabulated comparison (see Table 3) illustrates that the pervasive nature of computerisation into aircraft flight control ensures that the workload associated with operating the modern fly-by-wire aircraft is far less than in the conventional aircraft (Poprawa, 2011). However, Barker (2011) challenges this notion, by arguing that the new ease in aircraft control and overall workload, may manifest in pilot complacency or overdependence on the protections provided for by the computer-based systems. This presents the argument that when computer dependent protections are lost, pilots may find themselves in unfamiliar territory and unable to control the aircraft safely (Cockburn, 2007; Hradecky, 2011).

A search of the currently available database reveals that more research is required to ascertain the level of a pilot’s actual situational awareness loss with a loss in computer-based system protections. Bent (1996) has proposed that only from superior advanced aircraft training can there be assurances that pilots will remain competent whenever there may be a loss of protection provided for by advanced automation. Nonetheless, available statistics have shown that high automation in aircraft coupled with superior ergonomic flight deck design has resulted in far safer and financially viable air travel (Boeing, 2009; 2010).

2.3.4 Advanced airframe and mechanical subsystems

In the evolution of modern advanced aircraft, changes to the flight deck are conspicuous and very impressive. However, similar advances in peripheral systems, which constitute the advanced aircraft, are often unseen and hence neglected (Ishida & Kanda, 1999). Pilots’ misunderstanding or deficient knowledge loops in terms of aircraft systems have led to fatal accidents in the recent past. For instance, confusion about the auto-thrust system of an Airbus A320 contributed significantly to a TAM air crash in São Paulo, Brazil (NTSB, 2009). Chambers and Nagel (1985), as well as Koonce (2003), suggest that the mechanical elements of aircraft have become extremely reliable and can only conclude that the majority of accidents and incidents are significantly related to avoidable negligent human behaviour (see Figure 6). In other words, fewer accidents or serious incidents may be attributed directly to the aircraft itself.

Figure 6: The relationship between mechanical failures and human factors



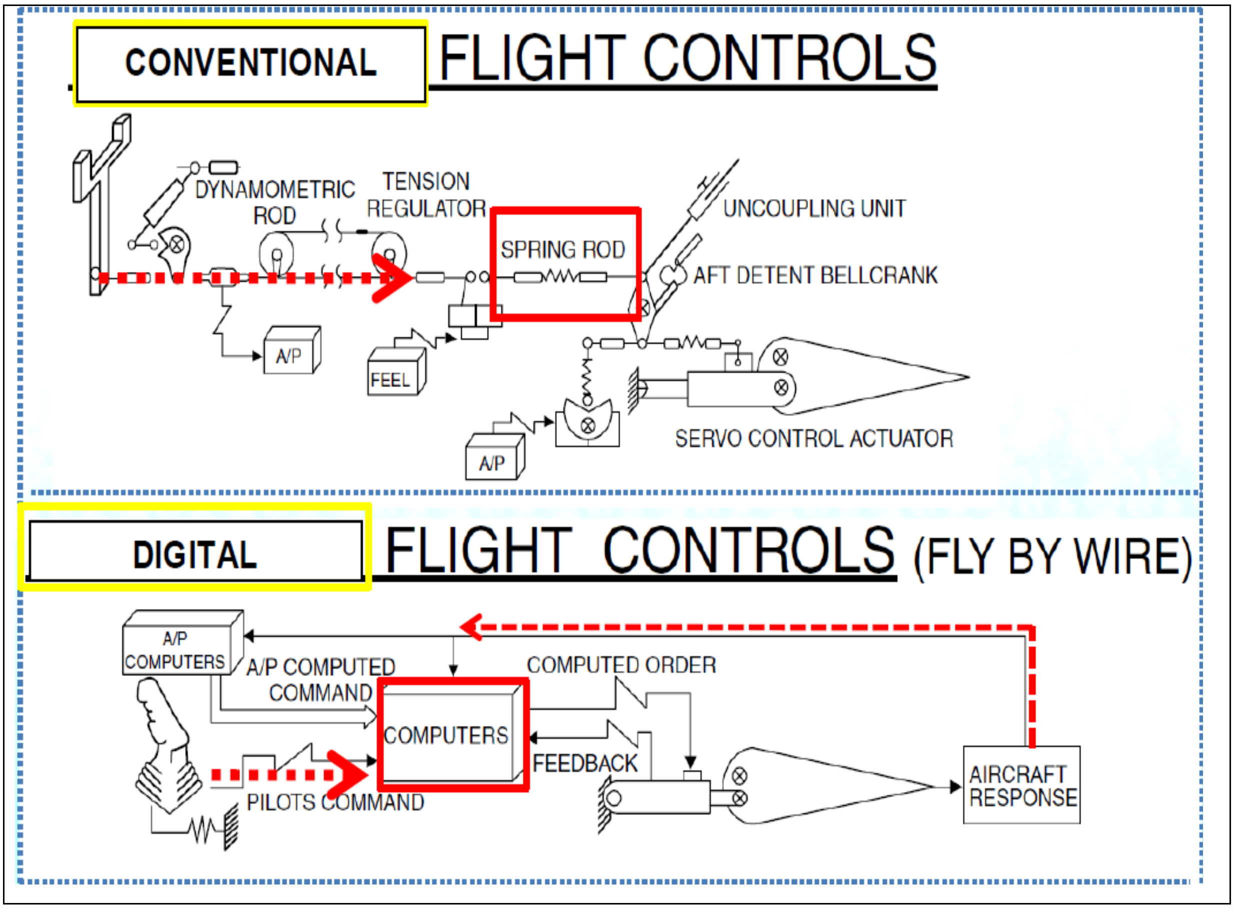
Source: Chambers & Nagel (1985)

The greatest changes to aircrafts' peripheral and airframe mechanical design arguably came in the form of the digital electrical flight control systems, also referred to as fly-by-wire (FBW). Briere and Traverse (1993) discuss how these computer-based, fault-tolerant (high redundancy) systems have enhanced the safety aspects of aircraft flight control substantially. Such a system first appeared in the Airbus A320 in 1988. Since then, more manufacturers have opted to computerise such mechanical subsystems, in the hope of increasing both safety and the savings resulting from greater efficiency. Pilots are now able to fly aircraft with unprecedented precision and accuracy, saving both time and money (Airbus, 2011b).

Yeh (1996) found that Boeing's triple seven (B777) aircraft's primary flight control system exhibited high levels of redundancy: "The heart of the FBW concept is the use of triple redundancy for all hardware resources: computing system, airplane electrical power, hydraulic power and communication path" (Yeh, 1996:294). However, this increase in efficiency, coupled with aviation safety requirements, derived from advanced computer programming, software and hardware, requires a paradigm shift in pilots' comprehension of systems. It is possible that changes can result in adverse human factor issues and have led to unforeseen problems according authors such as Billings (1997), Ishida and Kanda (1999), Parasuraman and Riley (1997) and Mitchell *et al*. (2009).

Figure 7 depicts the general differences in aircraft control design at a mechanical level. The actual mechanical linkages have now been replaced by a digital signal propagated through an electric wire in the modern aircraft. Furthermore, the figure depicts how manufacturers went from a direct link between the pilot and the flight control system to an indirect link, controlled and monitored by sophisticated computer-based hardware and software. One concern with these advances is that some accidents are now being attributed to incorrect pilot control of advanced FBW systems (Koonce, 2003; NTSB, 2009). The very design that was intended to prevent accidents is now being singled out as a major contributory factor to accidents.

Figure 7: Comparison of two aircraft control system types



Sources: Adapted from Airbus (2011a); Briere and Traverse (1993) and Yeh (1996)

2.4 AUTOMATED AIRCRAFT AND HUMAN PERFORMANCE

When increased automation of aircraft was first envisaged, Wiener (1993) argued that effectiveness, efficiency and flight safety would benefit substantively. This implied that there were financial implications for airline companies that chose not to operate modern equipment. It made business sense for both entrepreneurs and governments to invest in technology (Bainbridge, 1983). In consequence of these changes, it was predicted that over time, a number of pilots would have no choice but to transition from analogue to digital flight control systems (Bent, 1996; Chambers & Nagel, 1985).

The current body of literature points out that new human factor issues that are unique to technological changes are increasingly being raised by airline managers, accident investigators, civil aviation regulators and human behaviour experts (CAA, 2011; NTSB, 2009; Parasuraman & Riley, 1997). Poor interface design, human complacency, over-reliance on automation, a loss of manual flying skills, and pilots' general lack of understanding of design intentions and system logic are some of these human-related concerns.

One regulator's report into a serious incident involving an Airbus A340-300 aircraft in Johannesburg cited pilot training and a lack of understanding of the system design as direct and significant contributory causes of the incident (CAA, 2011). On further inspection of the training material (Airbus, 2011b) associated with this particular accident, it was determined that the recommendation to use a FBW tool linked to the side-stick control during lift-off could be confusing to pilots. A Maltese cross on the primary flight display was in no way correlated with the actual elevator or aileron flight control surface position, and was thus only an indication of side-stick deflection, which led to pilots' confusion on the flight deck. This illustrates how a relatively trivial component of the system (not anticipated as a problematic area to the design engineers) can lead to a critical breakdown in aircraft understanding by the pilots and subsequently to a serious incident.

The manufacturer has since updated the software logic to remove a part of the indicator that caused the human factor problem in this particular incident.

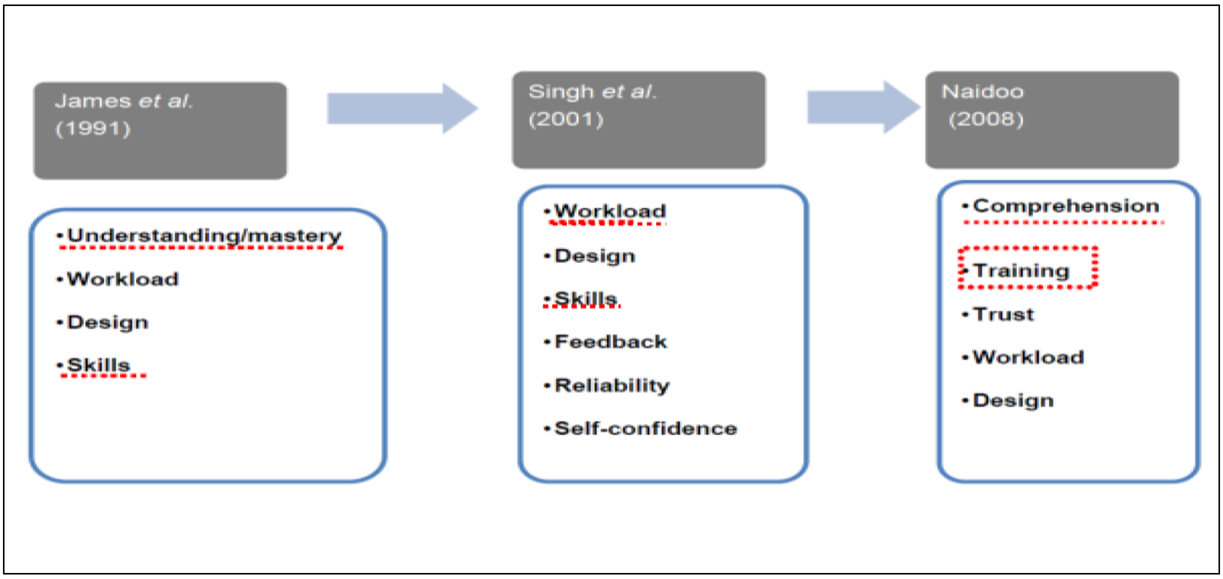
Furthermore, this incident draws attention to the fact that no amount of ground testing can ever cater for all possible permutations of the human-machine dynamic in actual flight. There will always be some combination of human-machine circumstances that may result in unforeseen outcomes (Rigner & Dekker, 2000).

In another serious incident involving complex peripheral subsystems, misidentification from a faulty computer processed fuel pump resulted in engine thrust loss (Hradecky, 2011). The monitoring computer of this aircraft received anomalous information and passed this information on to the crew. Ambiguity in the human-machine interface led the crew to shut down fuel pumps that were, in fact, functioning correctly. Fortunately, the crew were able to pick up the error after an engine rolled back, and they then disregarded the recommendations from the monitoring computer system, and were able to restore engine thrust. In this case, the human operators had sufficient knowledge and understanding of the system to avert disaster. These, and other similar incidents, serve to highlight the impact of automation on human performance.

Empirical research into airline pilots' experiences with advanced automated aircraft (the human-machine interface) spanning the last two decades shows that an undesirable human-machine relationship may be gradually emerging (Mitchell *et al.*, 2009). A comparison of three important automation-related aviation surveys confirms empirically that automation *training* is the new factor extrapolated from the item correlates. The emergence of this factor opens up a new research path in aviation psychology.

An analysis of the advanced automated aircraft training climate will provide some of the much-needed new knowledge in this direction. Figure 8 depicts the trend of factors revealed by the three surveys conducted over the last 20 years. The factors highlighted in the figure suggest the emergence of a mismatch between systems knowledge and design intentions – the training-related areas are clearly marked.

Figure 8: Trends in three aircraft automation surveys



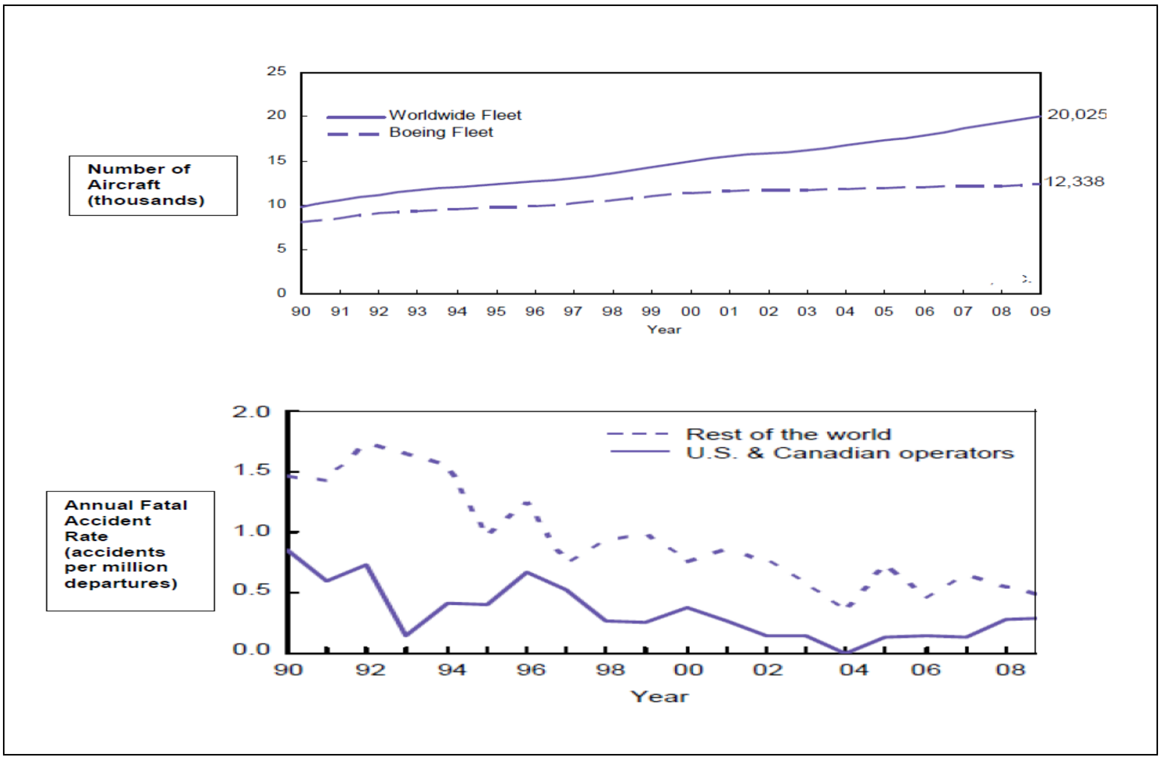
Source: Adapted from Mitchell *et al.* (2009)

The three surveys were used to collect empirical evidence about emerging issues related to advanced automated aircraft. Clearly, Figure 8 shows that the factor of *training* appears to have become a more important issue over the years as aircraft become more complex.

There are a number of general concerns about human beings' interaction with technology, as well as specific concerns, such as systems design and implementation. Examining the approximately 92 distinct automation issues affecting human operators substantiates this statement (Lyall & Funk, 1998; Parasuraman & Byrne, 2002; Parasuraman & Riley, 1997). Detailed discussions of these issues fall beyond the scope of this literature review – suffice it to say that the web database http://flightdeck.ie.orst.edu/ contains a quality discussion on specific topics which will be valuable in any research dedicated to advanced aircraft issues (Lyall & Funk, 1998:288). The database was formulated on the basis of evidence from accident and incident reports, experiments, surveys and other studies.

For the purposes of the present study, a review of the database was deemed essential for understanding the human-machine dynamic at a specific human-factors level. Reviewing the database also served as a guide for the development of various questionnaire items for the initial phase of the instrument development. The issues are verified and validated with empirical evidence from both qualitative and quantitative reports (see Tables 4 and 5). Independent research by the big aircraft manufacturers Airbus (2011b) and Boeing (2009) found that nearly 20% of human error accidents are directly related to the human-machine interface, and specifically to human interaction with on-board automation. Figure 9 compares the overall accident rate with the manufacturing rate of modern western-built commercial jet aircraft (over thirty tonnes).

Figure 9: Aircraft production versus accident rate



Source: Boeing (2009)

The study conducted by Boeing (2009) found that, although the use of advanced western-built commercial jet aircraft weighing over thirty tonnes has increased within the last two decades, the moving average accident rate for these aircraft has decreased substantially (see Figure 9). This decrease is ascribed mainly to advances in design and technology. However, even with exceptional technology, it appears very difficult to achieve the elusive zero accident rate, in part due to the adverse effects and contributory impact from the human factor (Dutch Safety Board, 2009; Machin & Fogarty, 2003). Although the accident rate is far lower with modern automated aircraft than with more traditional analogue-based aircraft in general terms; psychologists, researchers, pilots and aviation safety experts are still concerned about the breakdown in knowledge loops which lead to aircraft incidents and accidents in modern digital aircraft (Johnston *et al*., 1995; Machin & Fogarty, 2003).

Lyall and Funk (1998:291) list the following concerns regarding the human machine-interface, after quantification from various sources:

- pilots may place too much trust in automation;
- there has been a loss of manual flying skills; and
- pilot interface systems may be too complex for the average pilot.

Paralleling the aforementioned concerns, in an effort to pinpoint the issues, regulators and scholars in the field have also attempted to summarise the issues that affect flight crews' optimum use of automation (Airbus, 2011b; Helmreich, 1987; Parasuraman & Riley, 1997; Risukhin, 2001). The following issues were used to guide the present study toward an encompassing measurement construct:

- *being intimidated,* which may prevent pilots from taking over from the autopilot until a very late stage;
- *overconfidence in, or overreliance on, the autopilot,* which may make pilots delegate too many tasks to the computer too often;
- *inadvertent arming or engagement* of an incorrect mode;
- *failure to cross-check* and verify the armed automation mode;
- selection of *incorrect automation targets*;
- *a lack of discipline* in confirming selected automation targets on primary reference instruments;
- *a preoccupation with flight management programming* during critical phases of flight, with a consequent loss of situational awareness;
- *a lack of understanding* of the automation mode transition process and mode reversions, resulting in mode confusion (misunderstanding the autopilot); and
- *poor crew resource management* (CRM) practices, resulting in inadequate task sharing and monitoring.

2.4.1 The impact of human factors on aircraft safety

“Present technology is characterized by complexity, rapid change and growing size of technical systems. This has caused increasing concern with the human involvement in system safety” (Rasmussen, 1990:449). Some research suggests that organisational human error, and specifically pilot error has contributed to nearly half of all accidents involving western-built commercial aircraft above 30 tonnes (as depicted in Table 4). Furthermore, Table 4 illustrates comparatively the impact of human behaviour as a cause of accidents with various other non-human causes. Adverse weather-related phenomena and mechanical faults are regarded as threats emerging within the operating environment and which subsequently manifest into on-board crew related errors (Helmreich, 2002). It has always been the intention of advanced aircraft manufacturers to improve automation systems so as to assist pilots in dealing with non-human sources of environmental threats. Paradoxically however, some studies have found increased technology related human error such as automation complacency, when dealing with external threats such as adverse weather or substandard navigational facilities (Parasuraman & Byrne, 2002).

Table 4: Accident statistics for western-built commercial aircraft above 30 tonnes

Cause	1950’s	1960’s	1970’s	1980’s	1990’s	2000’s	All
Pilot Error	41%	34%	24%	26%	27%	30%	29%
Pilot error caused by weather	10%	17%	14%	18%	19%	19%	16%
Pilot Error caused by mechanical issues	6%	5%	5%	2%	5%	5%	5%
Pilot error total	**57%**	**56%**	**43%**	**46%**	**51%**	**54%**	**50%**
Other human related errors (air traffic controller errors, improper loading of aircraft, fuel contamination, improper maintenance procedures)	2%	9%	9%	6%	9%	5%	7%
Adverse weather	16%	9%	14%	14%	10%	8%	12%
Mechanical failure	21%	19%	20%	20%	18%	24%	22%
Sabotage	5%	5%	13%	13%	11%	9%	9%
Other	0%	2%	1%	1%	1%	0%	1%

Source: Adapted from National Transportation Safety Board (2009)

According to Helmreich (2002:18), human error can generally lead to an aircraft incident or accident if not “trapped” early. Therefore, any critique of human error requires some reference to aircraft incidents or accidents. For the discussion in this section, it becomes necessary to clarify the difference between an aircraft accident and an aircraft incident. The International Civil Aviation Organisation (2001) defines an *accident* as any occurrence associated with the operation of an aircraft where a person is fatally or seriously injured (except from natural causes, self-inflicted or from others, or injuries to stowaways), the aircraft sustains structural damage affecting flight performance, or requires major repair, or the aircraft is missing or completely inaccessible. An *incident* on the other hand, is regarded as an occurrence with the potential for affecting safety, which can lead to an accident.

Table 4 clearly shows how human factor issues, specifically those involving pilot error, should be a concerning factor for accident/incident investigators, regulators and operators. Pilot error can be regarded as a mistake, omission, commission, lapse, negligence or faulty judgment on the part of the pilot, which may lead to an incident or accident (Risukhin, 2001). Parasuraman and Byrne (2002) pointed out that the introduction of highly advanced commercial aircraft during the 1990’s have contributed to the increased human factor issues related to the accident rate, and this can be clearly seen from the descriptive statistics illustrated in Table 4.

A typical aircraft accident investigation, specifically those involving elements of the human factor, may last up to five to ten years and can still remain inconclusive even after many years of painstaking investigation, due to the complexities and controversies involved (National Transportation Safety Board, 2009). Investigating human error in aircraft accidents is a contentious issue, specifically when it involves highly advanced technology, as many players are subsequently associated; such as the operators, designers and managers, therefore not just the pilots (Rasmussen, 1990; Rigner & Dekker, 2000). The complexity arises from the complication in the relationships and interests between the various stakeholders involved in such an accident. For instance, manufacturers may want to blame the pilots; the airline companies may want to blame the aircraft; passengers and the families of the flight crew may want to blame managerial decision-making. Moreover, human factor-related incidents and accidents contain a fair amount of subjectivity when gross negligence or intentional non-compliance with procedure is not the case. Pinpointing the exact nature of human error on the flight deck when it involves interaction with high automation is difficult, particularly because automation was intended to relieve pilot workload (Singh *et al.*, 2005).

To put it simply, air crash investigations highlighting human factor issues relating to technologically advanced aircraft are complex because these investigations involve psychology and examining the two main advanced aircraft components. In analysing such accidents, incidents or mishaps, it was concluded that in general a distinction can be made between the automated systems affecting the pilot in the flight deck, such as electronic flight instrument systems (EFIS), the flight director (FD), navigation, or the flight control unit (FCU), on the one hand, and the advanced airframe mechanical subsystems, such as flight controls (FBW), hydraulics, electrics or electronic engine control, on the other hand. Table 5 and 6 was drawn up to highlight such distinction. These tables also summarise incidents involving some older analogue type aircraft automation systems, together with the more relevant advanced automated aircraft systems for more enlightening contrast. Although improvements were made in some systems after aircraft accidents, similar human factor and training problems continue to haunt modern digitised aircraft.

Table 5 shows that many of the incidents and accidents concerning automated flight deck systems involve the pilot's misinterpretation of the flight computer state. The phenomenon is called mode confusion. According to Parasuraman and Byrne (2002), the problem arises when there is a mismatch between a pilot's mental model of reality and the actual aircraft situation as interpreted by the flight computers. For instance, Table 5 goes on to list many accidents resulting from vertical mode confusion. In these cases, the pilots assumed that the aircraft would maintain a particular descent trajectory; however, in reality, many pilots continually select an incorrect autopilot mode, one of the major problems in the advanced flight deck. The aircraft however, would only perform as demanded by the pilot, resulting in a dangerous set of circumstances, such as idle thrust very close to the ground. Aircraft manufacturers therefore stress the importance of continually maintaining a high level of situational awareness through correct and accurate interpretation of the flight computers and subsequent aircraft state. For example, a core Airbus golden rule states that pilots should know (understand and interpret) the Flight Mode Annunciator (FMA) at all times (Airbus, 2011b). The FMA is possibly one of the most important indications of the current state of the aircraft in a glass flight deck and should be considered a primary instrument (Funk & Lyall, 2000).

Table 5: A chronological list of automation incidents and accidents related to the flight deck

Automated aircraft flight deck systems					
Year	**Location**	**Aircraft type**	**Operator**	**Description of incident or accident**	**System(s) involved**
1972	Miami	L-1011	Eastern Airlines	Loss of situational awareness after an inadvertent autopilot disconnection.	ALTITUDE HOLD
1973	Boston	DC-9-31	Delta Airlines	Pilots' preoccupation with questionable flight director led to a loss of situational awareness.	FLIGHT DIRECTOR
1988	Gatwick	A320	Air France	Vertical mode confusion.	FLIGHT CONTROL UNIT
1989	Boston	B767	Unknown	Vertical mode confusion.	FLIGHT CONTROL UNIT and FLIGHT DIRECTOR
1990	Bangalore	A320	Indian Airlines	Vertical mode confusion.	FLIGHT CONTROL UNIT
1991	Moscow	A310	Interflug	Inadvertent autopilot disconnection leading to confusion and loss of control.	ELECTRONIC FLIGHT INSTRUMENT SYSTEM
1992	Strasbourg	A320	Interair	Vertical mode confusion.	FLIGHT CONTROL UNIT
1993	Tahiti	B744	Air France	Inadvertent autopilot disconnection and vertical mode confusion.	NAVIGATION MODE
1994	Toulouse	A330	Air France	Unexpected altitude capturing during a simulated engine failure.	NAVIGATION MODE
1995	Connecticut	MD80	American Airlines	Inadvertently descended below minimum altitude.	NAVIGATION MODE
1995	Cali	B757	American Airlines	Incorrect input into the flight management computer resulting in aircraft impacting terrain.	NAVIGATION MODE
1996	Puerto Plata	B757	Birgen Air	Loss of control.	ELECTRONIC FLIGHT INFORMATION SYSTEM

Source: Adapted from National Transportation Safety Board (2009); Helmreich, 1987; Parasuraman & Riley, 1997; Risukhin, 2001

Table 6: A chronological list of automation incidents and accidents related to airframe subsystems

Automated aircraft mechanical subsystems					
Year	**Location**	**Aircraft type**	**Operator**	**Description of incident or accident**	**System(s) involved**
1984	New York	DC10	Scandinavian Airlines	Overran runway.	POWER PLANT
1985	San Francisco	B747	China Airlines	Inappropriate control of engine failure using the autopilot system.	POWER PLANT and ELECTRONIC ENGINE CONTROL
1988	Habsheim, France	A320	Air France	Loss of situational awareness in flight envelope.	FLY-BY-WIRE CONTROL SYSTEM
1989	Helsinki	A300	Kar Air	Inadvertent activation of Go-Around mode.	ELECTRONIC ENGINE CONTROL
1999	Warsaw	A320	Lufthansa	Overran runway.	POWER PLANT mode logic
1994	Hong Kong	A320	Dragon Air	Incorrect flap setting.	FLAPS MANAGEMENT SYSTEM
1994	Nagoya	A300	China Airlines	Aircraft inadvertently stalled on final approach.	ELECTRONIC ENGINE CONTROL
1994	Manchester	B757	Britannia	Inadvertent stall situation, recovered.	POWER PLANT and ELECTRONIC ENGINE CONTROL
1994	Paris	A310	Tarom	Aircraft inadvertently stalled then recovered.	POWER PLANT and ELECTRONIC ENGINE CONTROL
1994	Indiana	ATR72	American Eagle	Lack of knowledge in flight surface de-icing system led to inadvertent stall.	DE-ICING SYSTEM
1995	Bucharest	A310	Tarom	Aircraft entered a spiral dive situation.	ELECTRONIC ENGINE CONTROL
2008	Sao Paulo	A320	Tam	Overran runway after confusion with auto thrust.	ELECTRONIC ENGINE CONTROL
2009	Schiphol, Netherlands.	B738	Turkish Airlines	Inadvertent aircraft stall on final approach after thrust auto reduced to flight idle.	ELECTRONIC ENGINE CONTROL and AUTO THRUST
2009	Atlantic ocean	A330	Air France	Aircraft stalled after loss of flight information and autopilot.	FLIGHT CONTROL COMPUTER

Adapted from National Transportation Safety Board (2009); Helmreich, 1987; Parasuraman & Riley, 1997; Risukhin, 2001

Table 6 depicts a number of power plant- or engine-related problems. The full authority digital engine control (FADEC) system of many advanced aircraft is both a complex and highly efficient system, one which has allowed modern aircraft to generate profits for the companies that own these aircraft. It allows aircraft to be flown with such high precision, that fuel savings have increased substantially over the last 10 years. However, the high complexity of the system has also resulted in new and previously unheard of human factor errors when the system breaks down (Cockburn, 2007; Rouse & Morris, 1987).

2.5 AIRLINE PILOT TRAINING

The changing role of human beings' relationships with technology is partly a result of the blurring of boundaries between the technical and non-technical expertise required to perform effectively (Funk & Lyall, 2000). Rigner and Dekker (2000:318) suggest that a modern aircraft pilot (as opposed to a traditional "stick-and-rudder" pilot) is a proactive manager of a complex system. A modern airline pilot is required to resolve complex automation problems involving supervising, programming, monitoring, and cognitively deciding on tactics or strategies incorporated in an array of complex computers (Mosier *et al.*, 2007). The paradigm shift requires airlines to rethink their training regimes.

Caro (1998) contends emphatically that a basic requirement to meet the need for precision in flight training methods and syllabi is a systematic analysis of piloting tasks or the required competencies in a changing learning environment. Furthermore, it is argued that "imprecisely defined aircrew training programs cannot demonstrate the relevance and adequacy of their course content with respect to known training requirements and, therefore, [organisations] might be judged culpable in the event of errors committed by aircrews they trained" (Caro, 1988:249). Airlines have absorbed many of the aspects of training pilots on complex, advanced aircraft, such as transition training. Scholars in the subject are beginning to find it increasingly difficult to gain access to potential samples of airline pilots undergoing training on advanced aircraft, because airlines tend to limit access to outside researchers (Funk & Lyall, 2000; Rigner & Dekker, 2000).

Large airline organisations are commonly referred to as legacy carriers. Such carriers are inclined to employ only qualified and experienced pilots who are recruited to complete an organisationally structured training course to operate commercial aircraft in accordance with precise measurement outcomes (Taylor & Emanuel, 2000). Instructors tasked with training such airline pilots emphasise the technique of integrating known learning (in other words, how to fly older aircraft) with the unknown (how to fly modern digitised aircraft) by drawing on pilots' experiences (Bent, 1996; South African Airways, 2007). This strategy has proved fruitful in mitigating the complexities of modern aircraft training. In support of the strategy, the minimum experience levels required to join a legacy carrier are therefore extremely high. The effects of this recruitment policy are clearly noticeable from the demographics in the present study's sample frame.

2.5.1 Airline training strategies

Two types of initial training for airline pilots are commonly differentiated in the literature: pilots have either *civilian* or *military* training backgrounds (Taylor & Emanuel, 2000). Although military-trained pilots receive less team-based training during their initial flight training, they are considered highly experienced and skilful, and are thus much sought after by commercial airline companies (Bent, 1996). It is common knowledge in the aviation industry that military candidates complete an easily verifiable precision-based and highly structured training course (Andrews & Thurman, 2000). Powerfully regimented training programmes are very difficult to replicate in non-military settings (Caro, 1988).

In training an advanced aircraft pilot, it is the airline organisation that is generally responsible for a candidate's transition onto a new aircraft. This transition consists of three broad components. This multidimensional approach to training stratification consists of a theoretical learning part, a flight simulator training part and a route (or actual flying) part (Moore, Lehrer & Telfer, 1997). Flight simulation is possibly the most critical pedagogical aspect of an airline pilot's training (Pasztor, 2009). Since using a flight simulator is a critical and legal requirement for training pilots in unusual and emergency type scenarios or situations, it is discussed separately, in Section 2.5.3.

Converting trainees and maintaining their competence on a new aircraft type is generally accepted as the responsibility of the airlines that employ pilots. This conclusion is substantiated from a review of the literature which shows how empirical research consistently suggests that organisational level gaps in knowledge, misunderstandings and misconceptions, are responsible for a fair proportion of the problems and failures associated with airline pilot transition training (Lowy, 2009; Lyall & Funk, 1998; Parasuraman & Riley, 1997). Recently, the NTSB's severe incident report into an advanced aircraft issue found that the company-designed training material contained items that conflicted with some of the practices recommended by the manufacturer (Hradecky, 2011). Therefore, it is clear that misunderstandings and misconceptions of complex systems can frequently originate at the organisational or macro level. This invariably leads to significantly inappropriate behaviour at an individual (pilot) level at an operational level (Patrick, 2002). Scientific examination and research into the learning environment may give investigators insight into these and other problems.

Maintaining a competitive advantage in an industry with very narrow margins implies that businesses must, and do, invest in new technology (Australian Transport Safety Bureau, 2007). Funk and Lyall (2000) found that the technological complexities of automated aircraft mean that organisations will continuously teach new skills to pilots or (re)train pilots and that "increased levels of automation with the advent of the *glass cockpit* have resulted in substantial changes in the way civilian aircrews are trained" (Taylor & Emanuel, 2000:18, own emphasis).

Training can be an expensive exercise for an airline business, and therefore it should be regarded as an investment for the long term. The typical airline organisation would therefore invest in various critical resources to meet current and future training demands. These resources, according to Caro (1988), include assets such as personnel to conduct the instruction, operational aircraft, simulators (or other aircraft representations), printed or graphic media, classrooms or practice areas, and variations of other specialised aids or devices. The resources chosen all depend on the tasks that pilots need to master. Some researchers argue that a paradigm shift is needed in how organisations train pilots for advanced automated aircraft in order to meet the needs of humans in understanding complex computerised systems (Funk &

Lyall, 2000; Naidoo, 2008; Rigner & Dekker, 2000). Therefore, it may be necessary to change, enhance or develop new training materials for the advanced aircraft.

Previous research has found that airlines are slow to make relevant changes to training methodology. For example, combating “automation bias and complacency”, particularly with very experienced advanced aircraft pilots, is an area of training, which airline organisations often seem to neglect (Mosier *et al*., 2007:301; Naidoo, 2008:110). The emphasis is still placed on training aspects related to an earlier era of aircraft, such as engine failure and manual handling skills, which include trainees’ demonstration of conducting accurate steep turns (banking the aircraft outside of its normal operational envelope). Some authors argue that the reliability of aircraft engines is such, that less than 1% of airline pilots will experience an actual failure on the line, so more emphasis should be placed on handling automation failure rather than on manual control of an engine failure (O'Hare *et al*., 1994). Some authors suggest that it is bizarre that a pilot of a highly advanced aircraft should have to demonstrate to the regulators an ability to fly the aircraft outside its normal operating range in order to receive a licence (Lyall & Funk, 1998; Poprawa, 2011). For example, pilots may still have to prove that they can accurately perform a steep turn, which pushes the aircraft beyond its normal bank angle (when such a manoeuvre is accomplished fairly easily in modern fly-by-wire aircraft such as the Airbus family, and therefore demonstrates very little skill). These and other similar debates illustrate the level of uncertainty in training pilots to fly advanced aircraft.

2.5.2 Models of airline instruction

In response to the systemic nature of training and instruction in a modern airline, Spector and Muraida (1997) suggest that models of Instructional Systems Development (ISD) or Systems Approach Training (SAT) be consulted in planning multidimensional learning environments. The systems methodology of pilot training was reviewed based on the systemic approach to the research construct (discussed in Chapter 3). The systems training method is thought to maintain the precision required for advanced aircraft pilot training (Bent, 1996). These models are used extensively and have served the advanced aircraft training community well over the last decade (Panda, 2003). Operationalization of the construct to measure the advanced aircraft training climate in the current study was similarly multidimensional. Andrews and Thurman (2000) argue that aviation training organisations may justify deviating from the prescriptions of a particular multidimensional structured ISD model only for logical reasons. The current literature suggests that the effects of such training methodological decisions are not yet fully understood, but anecdotal evidence suggests that following an ISD model too closely can in itself present some dangers – for example, Hradecky (2011) reports that crew can be incorrectly trained (albeit to company standards) to deal with complex aircraft problems.

Table 7 is presented as a synthesis of some important models suggested by various experts whose work contributed to building the initial research framework.

Table 7: Chronological synthesis of Instruction Systems Design models (ISDs)

Source	Model Description
Spector and Muraida (1997:67)	1. Conduct a needs analysis. 2. Design the course. 3. Produce the programme. 4. Implement the course. 5. Continually maintain the course.
Pohlman and Fletcher (1999:297)	1. Analyse the job by asking what knowledge skills, outcomes, and attitudes are to be produced. 2. Design the instruction and devise the instructional interaction. 3. Produce, develop and prepare the instructional materials. 4. Install and implement an appropriate training system. 5. Evaluate, verify and validate the instruction.
Patrick (2002:439)	1. Identify the training needs and required tasks that need to be trained from qualitative and quantitative accident/incident analysis. 2. Design the training based on appropriate psychological principles and theories to promote motivation and ensure learning transfer. 3. Evaluate whether the training programme has actually achieved its intended objectives.
Panda (2003:129)	1. Analyse the training requirements. 2. Design the training programme. 3. Develop the course. 4. Implement the training programme. 5. Control the training programme.

An examination of the models in Table 7 reveals that the frameworks suggested all contain some version of the steps commonly employed in systems engineering designs (Panda, 2003). The ISDs are thus a scientific approach to training. The sample used in the current study consisted primarily of organisations that conform to the basic ISD framework. The use of an ISD model in an aircrew-training environment is based on psychological, philosophical and pedagogical orientations (Pohlman & Fletcher, 1999). Therefore it makes intuitive sense that an ISD will generate competent pilots more often than not. For these reasons, analyses of such frameworks were deemed pertinent in the present research approach in designing an appropriate measurement construct.

Approaching an analysis of the aviation environment in a scientific and systemic manner can ensure that operators are as objective as possible in training, assessing skills, and overall in qualifying competent pilots.

2.5.3 Flight simulator training

Meister (1999) contends that the pilot and the aircraft are fundamentally and critically interrelated as a system. Therefore, indirect aviation measures of human performance can be extracted from the state of the aircraft, or in a training situation, of the experiences in a flight simulator (Bonner & Wilson, 2002). For instance, Dahlstrom and Nahlinder (2006) suggest that there is immense value in using flight simulation as a source of information to improve basic civil aviation training. Therefore, a core modern training device employed by airline organisations for the structured training of advanced aircraft pilots is the flight simulator, or synthetic training device (FSTD). Furthermore, FSTDs are a legal requirement for training pilots engaged in any commercial flight operations at airline organisations (Civil Aviation Authority, 2011).

The first aircraft flight simulator was built before World War I to simulate the Antoinette monoplane (Rolfe & Staples, 1986). Flight simulators and various synthetic training devices will continue to play a critical role in training the modern or advanced aircraft airline pilot, today and for the recognisable future (Magnusson, 2002). This component has in turn made a significant impact on how pilots experience their overall aircraft training (Telfer, Moore & Farquharson, 1996). The core intent in the usage of the aircraft flight simulator is possibly to ensure that the simulation should accurately mimic reality as closely as possible (Howell & Fleishman, 1982). However, Dahlstrom and Nahlinder (2006) found sufficient evidence that the mental workload to perform in a flight simulator is far less than that required in actual aircraft flight, which suggests that there may be a mismatch between simulation and reality. Flight simulator realism nonetheless, is based on a basic simulation structure in three parts, as proposed by Rolfe and Staples (1986:4):

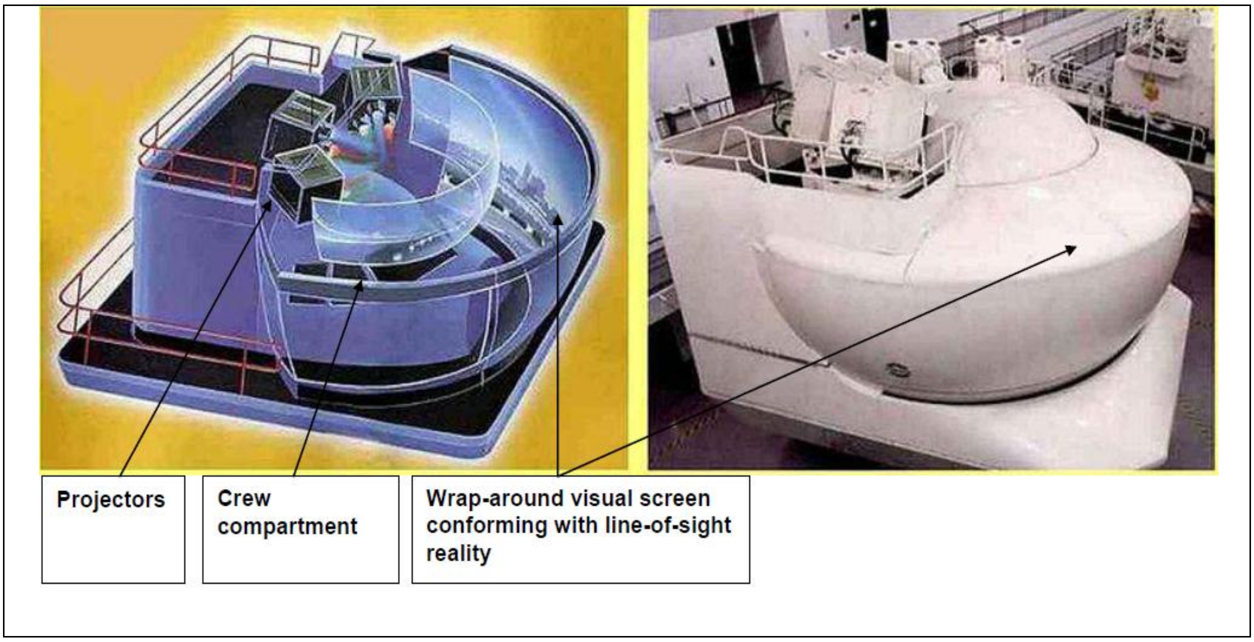
- a model of the system to be simulated;
- a device through which the model is implemented; and
- an applications regime to satisfy the combination of the first two elements in such a way as to meet the training objectives.

If any of the aforementioned components are missing, it may be expected that the gap between simulation and reality should increase. More research may be needed to compare flight simulation to actual aircraft flight in order to determine precisely the level of disconnect. This may have consequences for programmes such as the MPL (Multi Pilot Licence). The MPL entails reducing a trainee’s actual aircraft flight experience by replacing it with flight simulation time as a method to expedite pilot training (ALPA-SA, 2011).

Pilots are permitted to practise emergency and unusual situations only in an aircraft flight simulator, and not in the actual aircraft, due to safety considerations (Civil Aviation Authority, 2011). The details of these procedures for licensed pilots and training organisations are found in the primer stipulating the international civil aviation regulations and technical standards for all signatories of the Chicago Convention (International Civil Aviation Organisation, 2011), which includes the majority of countries operating modern western-built commercial jet aircraft.

The theory of common elements and transfer surface forms the basis of the simulation concept. Projectors and wrap-around visual screens in modern flight simulators attempt to mimic reality closely (Rolfe & Staples, 1986). Technologically modern FSTDs employ high resolution, computer-generated colour images, operating in multiple degrees of freedom (Howell & Fleishman, 1982). The realistic appearance of the synthetic flight deck (Figure 10) suggests that operational transfer will occur to the extent that there should be definite commonalities between the simulator and the aircraft (Thorndike, 2007). Evidence from some experiments confirmed a strong correlation between elements, or features, contained in the simulator and the features of the actual equipment, suggesting that a transfer of training is positive or high from an advanced FSTD (Bonner & Wilson, 2002; Caro, 1988). Therefore, airline operators and instructors are extremely confident about the level of training received by their pilots and its transferability to the actual aircraft. There may be a strong financial incentive for organisations to use modern simulators, because operating the actual aircraft to obtain licence ratings is no longer a prerequisite. Indeed, confidence in the accuracy of the FSTD is so high that regulators allow a pilot to obtain a licence for an advanced aircraft without having flown the actual machine. The level of psychological connection or disconnection experienced by the trainee pilot between an FSTD and the actual aircraft is therefore an important area for further investigation.

Figure 10: Modern flight simulator training device



Source: Adapted from Stevens and Lewis (2003) and Strachan (2011)

The crude combination of appropriate levers and linkages in the first monoplane flight-training simulator has since evolved significantly, into a highly sophisticated synthetic device in an attempt to replicate reality as accurately as possible (Figure 10). Advances in simulation techniques provided by computer, materials and engineering technology attempt to recreate a supposedly seamless integration between the FSTD and actual aircraft fight (Magnusson, 2002). Such training is commonly referred to as zero flight time training (Stevens & Lewis, 2003). However, contradictory findings suggest that simulator transition training is not and can never be a completely seamless exercise, as there are always gaps between reality and simulation (Singh, Sharma & Singh, 2005).

One of the main problem areas, which result in such mismatches, stems from the fact that trainees can pre-empt an emergency exercise in the flight simulator, whereas this is not the case in actual aircraft flight. Therefore, it was found that the heart rate and mental workload of pilots in simulated exercises do not completely correlate with that in actual aircraft flight (Dahlstrom & Nahlinder, 2006). Nonetheless, Go, Bürki-Cohen and Soja (2003) found that the full motion simulator did indeed make a statistical difference to the evaluation of pilots; however, it played only a middling role in actual pilot training. Perceptions of training in a flight simulator may then be affected. In other words, because all aspects of flight training for an advanced aircraft cannot take place in the actual aircraft, it may be concluded that simulators may influence pilots' training experiences either negatively or positively. Therefore, one of the secondary goals in the current research was to gain further understanding of the phenomena associated with the use of flight simulator training devices.

2.5.4 Pilot route training

Caro (1988) and later, Go, *et al.* (2003), found a significant relationship between training utilising an FSTD, to the training gained from actual aircraft flight. In order for an airline company employing an advanced aircraft pilot to gain sufficient evidence that this transition (from simulation to reality) has indeed been successful, route training is mandatory for a new pilot on aircraft type (South African Airways, 2007).

Route training generally consists of flying a predetermined number of sectors in normal operations to ascertain the level of competence the trainee has achieved from the FSTD (SAA, 2007). The candidate is required to complete a number of tasks in the real aircraft with an instructor present. Exercises such as landing the aircraft with varying flap settings, cross-wind approaches, landings and take-offs in adverse weather and other normal operations are completed by the trainee pilot, where after the pilot is deemed fit to operate the aircraft in normal line operations.

Airline training organisations are well aware of the divide that may exist between flight simulation and actual aircraft flight (Thorndike, 2007). This has made actual aircraft flight training in the form of route training, a mandatory requirement in qualifying an advanced aircraft pilot. With this in mind, it was therefore necessary to probe trainees' perceptions in terms of both their experiences in the synthetic training device and in actual aircraft flight.

2.6 CONCLUSION

The literature review has highlighted the current lack of empirical academic knowledge of the psychology associated with advanced aircraft training. More objective scientific research is needed to answer the following question posed by Barker (2011:4): "Is automation error going to be the new human factors contribution to accident statistics?" Many analyses associated with advanced aircraft training were inconclusive regarding the psychological attributes that affected such training. The current study proposes the proposition that technological complexities in advanced automated aircraft have resulted in a shift in the role being played by human beings within the human-machine dyad. The competence required from pilots in respect of both their technical and non-technical abilities when operating advanced automated aircraft suggests that a paradigm shift is needed in the way organisations view their training regimes.

The chapter has mentioned the economic and safety motivations behind increased aircraft automation and some of their implications. Any advances in aircraft-related technology need to go hand in hand with new or additional training requirements and resources such as synthetic flight simulation devices. Effective and efficient training is a critical component in enhancing overall flight safety by mitigating the effects of human factor issues. It was found that the literature supports the premise that changes to the flight deck have resulted in unforeseen human factor issues. Because these issues are not easily designed out of aircraft, a close relationship is required between research psychologists and engineers.

It appears that airline organisations are slow to adapt to changes in the external environment, specifically in terms of training paradigms. Traditional transition training has made it difficult for scholars to assess fully the multivariate phenomena present in the systemic and rapidly evolving aviation environment. More importantly, the literature review reveals a real need for an appropriate psychological assessment scale to measure the training aspects of constructs associated with training pilots to fly advanced automated aircraft.

Determining what constitutes a suitable training climate for technologically complex systems may make it possible to understand the psychological and behavioural components of exactly what new knowledge acquisition is, and the subsequent transfer of learning into safely managing advanced machinery. Hence, the chapter examined, in behavioural terms, advanced flight deck automation. This was followed by a discussion of how airline pilots possibly undergo training for new technology. The review suggests that the synthetic flight training device or FSTD (flight simulator) is critical in teaching the modern airline pilot how to perform many tasks. This chapter has examined the complexities associated with an advanced aircraft training environment. The literature shows that the introduction of human beings into such an intricate environment induces a new dynamic, created by both psychological and behavioural components. In order to scientifically measure phenomena related to these components, it is necessary to operationalize an appropriate construct (see Chapter 3). The scientific measurement of constructs provides an avenue for specific and focused findings, rather than general or global discussion. Therefore, the next chapter presents and discusses the organisational, instructional and individual aspects required for developing appropriate theoretical models to meet the study’s objectives.