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Pilot Situation Awareness of Commercial Aircraft Flight Management Systems

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ABSTRACT

Complex, dynamic domains present an individual with a challenging operational environment. To be able operate effectively and achieve a desired goal, an individual must understand what is taking place in the surrounding situation. This task can become very demanding when the status of many elements in the situation may be continually changing simultaneously. The awareness and individual possesses of this situation is recognised as a fundamental prerequisite to achieve consistent proficient performance, and is the focus of this study.

Specifically, this study set out to evaluate the Situational Awareness (SA) that experienced commercial pilots possess of aircraft Flight Management Systems (FMS). To achieve this objective the Situation Awareness Global Assessment Technique (SAGAT), developed by Endsley (1995a), was adapted to the commercial FMS cockpit environment. This required development of a query database and design of an administration technique suitable for use in this study.

The increasing use of automation in the aircraft cockpit has produced some stunning improvements in operational efficiency. However, the increasing complexity of aircraft management systems has exposed problems associated with the operator-automation interface. Current FMS have evolved through the integration of several separate aircraft flight control systems to provide the pilot with a capable semi-autonomous flight management tool. While the introduction of these tools has helped to improve safety, they have also introduced some unexpected operational consequences. One of these consequences is the tendency for flight-crews to experience automation surprises. Such events occur when the automation's behaviour violates the operator's expectation, and are usually the result of an inconsistency between the operator's understanding of the system and the actual status of the system. In essence, automation surprises arise when the operator has poor SA of the system with which they are working.

Due to the limited number of evaluations that were completed during this study no conclusive findings could be made. Despite this, the data revealed that the automation appeared to dominate the participant's attention and, that relevant flight instructor experience could have beneficial effects on SA related knowledge.

Attempts were also made to determine if there was any correlation between SA and psychological motivation. However, in isolation the results from these tests did not show any promising relationship. Despite this, the prospect that psychological state might influence SA cannot be eliminated due to a lack of data available from the present evaluation. Furthermore, one of the participants displayed very different motivation results that could imply that a combination of motivational states might have an affect on an individual's SA.

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CHAPTER 1: INTRODUCTION

1.1 A Brief History

Like many technology-based disciplines in the twentieth century, development in aviation advanced at a staggering pace. Since the Wright brothers first flew, seemingly impossible dreams have become reality. Aircraft have conquered the sound barrier and carry millions of people around the world each year, all of which has occurred in barely 100 years. In recent times one of the most significant advances in aviation has been in the area of integrated automatic flight control systems.

Automatic flight control systems are as old as aviation itself. The Sperrys, an American father-and-son team, developed the first aircraft stabilisation system between 1910 and 1912. The Sperry system could simultaneously maintain both pitch and roll attitudes set by the pilot. At that time the need for automatic control systems to stabilise the aircraft arose from the inherently unstable design of the aircraft themselves (McLean, 1990). However, improvement in aircraft design and the weight penalty imposed by these early systems resulted in limited use of autopilots, as they were termed, in the flying machines of the day.

The next era of intense auto-flight system development occurred between 1922 and 1937 (Billings, 1991b; McLean, 1990). During this period companies began to employ aeroplanes on commercial operations to take advantage of the higher speeds afforded by heavier-than-air aircraft. However, commercial operations demanded a significant increase in mechanical reliability, and the ability to operate in all weather conditions. As aircraft manufactures began to produce aircraft capable of satisfying these commercial demands, the instrumentation required in the cockpit also increased rapidly. In combination with higher aircraft speeds, the proliferation of cockpit displays considerably increased the pilot's workload. This increase in workload was illustrated by the practice, used in early commercial aircraft during bad weather, where the pilot and co-pilot often found it necessary to divide the flying task between them. The pilot would assume control of the aircraft heading and track, while the co-pilot would control the aircraft's airspeed and altitude (McLean, 1990). The industry soon realised that these demands needed to be reduced in order to increase safety, and in turn, increase

public confidence in a fledgling aviation industry as a reliable means of transport. The result was the development of better autopilot systems.

Up until the 1970's the primary driving force behind aviation development had been predominantly the attainment of higher safety standards; a goal that pervades the industry to this day. However, in 1973 other forces began to emerge. Due to rising fuel prices, economic pressures began to rival safety as the dominant force driving aviation and auto-flight system development. The 1973 oil crisis forced airlines to re-evaluate how they utilised their aircraft in an attempt to control fuel costs. Obviously, the most direct way to reduce fuel costs was to reduce the fuel burnt by the aircraft itself. Unfortunately, immediate improvement in engine efficiency could not be expected, which left the airlines facing the dilemma of how to improve operating efficiency. To help them achieve this goal the airlines turned to the relatively new computer industry for solutions. The result was an array of cockpit systems that could provide the crew with information on best speed, altitude and routing to minimise fuel burn (Fishbein, 1995). These systems have evolved into the highly autonomous Flight Management Systems (FMS) of current glass cockpit airliners. However, the increasing autonomy and ability of the aircraft systems presented a new range of human-machine engineering challenges for aircraft crews and designers. The impact on the aircrew's duties has been most profound, changing the pilot's role from a "hands on" integral part of the flight control loop, to a supervisory controller managing a flight control system. Acting as manager, the pilot's knowledge of specific flight parameters becomes less significant, and the overall picture of the situation becomes increasingly critical. In general terms, this overall picture of environmental factors has become known as Situation Awareness (SA).

1.2 Situation Awareness

There are as many definitions of SA as there are disciplines that recognise the critical role a person's understanding of the environment contributes toward successful task completion. However, despite this diversity, virtually all of the reported definitions involve, to some extent, one or more of the following elements; perception of environmental stimulus, understanding those stimulus in light of operator goals, and the ability to anticipate future states of the environment (Artman, 1999; Carretta, Perry, &

Ree, 1996; Endsley, 1995b; Endsley, 1995c; Fracker, 1989; Hartman & Secrist, 1991; Judge, 1992; Sarter & Woods, 1992; Secrist & Hartman, 1993; Selcon, Taylor, & Koritas, 1991; Waag & Houck, 1994; Woods, O'Brien, & Hanes, 1987; Woods, Sarter, & Billings, 1997). These abilities are particularly useful in highly dynamic and time critical environments (Endsley, 1995b; Woods et al., 1987), of which aviation is a good example.

A report prepared by a Federal Aviation Administration Human Factors Team stated that “Inadequate assessment, understanding, or monitoring of any of these [aeroplane status and its systems] parameters contributes to deficiencies in SA, and may lead to inappropriate flight crew actions.” (Abbott, Slotte, & Stimson, 1996, p43).

1.3 The Flight Management System (FMS)

Before proceeding any further it is important to define exactly what is meant when talking about the Flight Management System (FMS), and what abilities the system possesses. Fishbein (1995) said, “a flight management system, in the context of this definition, comprises the sensors, displays and associated subsystems used to process and record flight information” p xxi. According to the Boeing 737 Operations Manual (Boeing Commercial Airplanes, 1987, p19.40.20), “the FMS is comprised of five component systems;

- Flight Management Computer (FMC) system.
- Alternate navigation system (as installed).
- Autopilot/Flight Director System.
- Autothrottle.
- Inertial Reference System (IRS).”

For the purposes of this research the definition provided in the Boeing Operations Manual will be adopted. As such, when the term FMS is used it is meant to include the IRS, the autopilot computer and actuators, the auto-throttle computer and actuators, and the FMC. These systems integrate with each other to form a flight control system that possesses a hierarchical structure. In this structure systems further up the tree are not able to perform their function without the systems below operating normally. In this way the IRS is the foundation of the system, it provides attitude reference to stabilise

the aircraft and calculate aircraft motion. Without the IRS no other FMS systems are available. The next layer operating directly above the IRS consists of the autopilot and auto-throttle systems. These systems control the actuators that manipulate the aerodynamic flight control surfaces, and engine power settings respectively, to maintain the desired performance. For example, the autopilot would attempt to maintain a commanded rate of descent by controlling the aircraft pitch attitude, while at the same time the auto-throttle system would control engine thrust to maintain a desired airspeed. These systems are independent of each other, and work to maintain their commanded targets without reference to the other. However, neither would be able to operate without the information provided by the IRS. The highest layer in the FMS tree is provided by the FMC, which acts as a supervisory controller of the autopilot and auto-throttle. In this role the FMC calculates the performance required to achieve programmed flight targets, and then commands the autopilot and auto-throttle to achieve the calculated performance (Figure 1). Again, without the IRS operating and the autopilot and auto-throttle engaged the FMC is not able to control the aircraft.

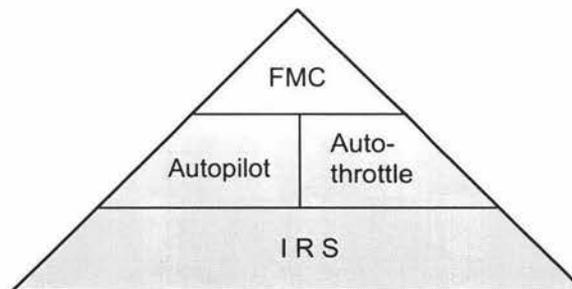


Figure 1: Hierarchy of FMS systems.

Because the FMS consists of several independent systems working in concert, information on each system is also independently displayed and often widely distributed around the cockpit. Consequently, the monitoring requirements imposed by these new tools can threaten to overwhelm the pilot, especially during already high workload phases of flight (Endsley, 1987; Endsley, 1995c; Funk et al., 1999).

1.4 FMC Control

It is now accepted practice to allow the FMC to determine the optimum flight level, calculate vertical and horizontal flight profiles and to control engine power settings. This gives the FMC considerable authority over the aircraft when engaged to command

the autopilot and auto-throttle. However, even though the FMC may be engaged to command the autopilot, the autopilot computer retains some responsibility for ensuring that aircraft performance limitations are not exceeded. If, for example, the autopilot computer detects that any of the FMC commanded flight targets would result in the aircraft exceeding a performance limitation, it has the authority to change the engaged mode. For instance, an FMC vertical navigation mode would revert to an autopilot speed mode if the FMC commanded rate of descent would result in the aircraft exceeding its maximum operating speed. Mode changes that occur in this manner are called mode reversions.

It should be noted that FMS mode reversion to prevent the aircraft from exceeding a performance limitation is very different to envelop protection on Fly-By-Wire (FBW) aircraft. FBW aircraft use computers to process all commands that are intended for the aerodynamic flight control surfaces. The logic programmed into these computers prevents flight control deflections that would result in the aircraft exceeding a performance limitation regardless of the input received by the computers. For example, it is theoretically impossible to induce an aerodynamic stall on a FBW aircraft that has envelop protection. This is an important distinction, as even commands made by the pilot when flying manually using the yoke or side-stick are subject to the restrictions imposed by envelop protection. Whereas, mode reversions only prevent the FMS from exceeding the aircraft's performance limitations by automatically changing the active autopilot mode.

The proceeding discussion briefly demonstrates that the FMS can operate as a highly autonomous system with considerable authority over the aircraft. However, despite all the abilities that the FMS possess, it is not necessarily an intelligent system. The FMS is essentially ignorant to environmental factors outside the aircraft, and is therefore operating in an inward looking reactionary manner. In the case of mode reversions this can be particularly troublesome. For example, the autopilot would force a mode reversion even if the new mode might compromise flight safety due to other environmental factors, such as a traffic or terrain conflict. As long as the FMS does not have the ability to see the big picture, or anticipate changes, human pilots and their SA, will always be an essential part of the flight environment (Rodgers, Covington, & Jensen, 1999). Because of this, the human and machine elements of the system must be

able work together effectively. Just as cockpit resource management (CRM) has focused on better human-human communications and teamwork (Wiener, Kanki, & Helmrich, 1993), greater effort should be made to improve human-machine communication and teamwork. Autonomous systems must become part of the team, not a replacement for the team (Billings, 1991a; Mosier, Skitka, Heers, & Burdick, 1998; Wiener & Curry, 1980).

1.5 Understanding Gap

The pilot's role in commercial aviation has changed dramatically since the first operations that dared to use aircraft to carry fare-paying passengers. Today, advanced FMCs coupled to very capable autopilots assume responsibility for controlling the aircraft in many, if not most, situations. In addition, the FMS generates a considerable quantity of information that contains a high degree of underlying complexity. Providing flight data in a more processed, or complex form, is done to reduce the cognitive load placed on the aircrew. However, as a result the information processing strategies employed by pilots have also undergone a fundamental change. Pilots have become managers of an increasing complex flight system (Sarter & Woods, 1992; Woods & Roth, 1988). The focus has gone from flying an aeroplane about the sky, to managing an aircraft through a complex flight environment. In this new management role pilots operate the aircraft, in a sense, by remote control. By selecting FMS modes on a control panel the system is initiated to fly the aircraft in the desired manner. However, system operation is complicated by the increasing autonomy of most modern FMS. Automatic mode changes occur for several reasons that range from mode reversions (as discussed), to mode captures where a new mode may engage upon reaching the current flight target. If the pilot is not kept well informed of these changes an understanding gap can develop that has significant implications for the safe conduct of the aircraft (Parasuraman, Molloy, & Singh, 1993; Parasuraman & Riley, 1997; Sarter & Woods, 1997).

Because the pilot remains responsible for safe operation of the aircraft at all times, his/her understanding of FMS status is vital to anticipate how the aircraft will behave in the future. Several factors can result in a gap developing between the pilot's expectations of how the FMS *should* fly the aircraft, and how the FMS *will* fly the

aircraft. The following points outline some of the factors that can lead to an understanding gap;

- ▲ Selection of a mode to capture a required flight parameter when the aircraft is outside of the capture criteria, and will not enter the capture area for that mode. Failure of the crew to detect this problem can result in the aircraft deviating considerably from the desired flight profile.
- ▲ Failure to engage an FMC mode after programming the FMC for the next flight segment. This is usually an omission error; for example, the crew may disengage the FMC while the new route is being programmed, and then omit to re-engage the FMC mode once the new route program has been completed. The effect on the flight profile is often subtle and not easily detected until the desired flight path changes significantly (ie; the aircraft may fail to turn automatically overhead a waypoint).
- ▲ Failure to detect a mode reversion, either due to non-vigilance or high workload, will result in the aircraft not following the profile the pilot expects. Often mode reversions are only detected when the aircraft fails to take an expected action, or when the aircraft preforms an unexpected action. This can cause considerable confusion while the crew establishes the reason for the disparity.
- ▲ Attempts by the crew to select a mode that is not available at that time, or is incompatible with other engaged FMS modes. This can lead to engaged modes becoming disabled, leaving the aircraft in a passive non-command autopilot mode. Under conditions of high workload the disengagement of autopilot command modes can go undetected, which has potentially severe consequences if the aircraft is on the later stages of a non-precision approach.

1.6 Communicating FMS Status

To reduce the possibility that a gap can develop between the pilot's mental model of the system's status and the actual situation, FMS status needs to be effectively communicated to the pilot. This is currently achieved by a display called the Flight Mode Annunciator (FMA). The FMA displays alpha character abbreviations for the

currently engaged FMS modes, and is usually located on the Primary Flight Display (PFD) (Figure 2).

<i>Auto-throttle engagement</i>	<i>Roll Mode</i>	<i>Pitch Mode</i>	<i>Autopilot engagement</i>
MCP SPD	HDG	V/S	AP

Figure 2: Example of a Boeing aircraft FMA display when the autopilot and auto-throttles are engaged and the aircraft is flying a selected vertical speed on a selected heading.

Despite the useful information provided by the FMA, it contains very little predictive information regarding the intentions of the system, or information regarding FMS modes that are available for the pilot to select (Woods et al., 1997). This leaves the pilot with the task of determining what the FMS will do in the future, which can only be done after evaluating information and settings in other rather widely dispersed areas of the cockpit. Consequently tracking system changes, and predicting future actions is a challenging integration task.

However, the FMA is not the only place where mode engagement information can be found, as the crew can reference the mode select buttons directly (McCrobie et al., 1997). Unfortunately, monitoring mode select buttons is a flawed method to determine FMS status, and can lead the pilot to form an inaccurate picture of the system. An inaccurate understanding of FMS status can arise from the need to interpret and integrate the functions of highlighted mode select buttons to determine armed modes and auto-throttle engagement. In these cases more than one button will relate to the systems status for roll or pitch axis control. Therefore, to form a correct understanding of how the system will behave the pilot must first identify those highlighted mode buttons that relate to pitch or roll control, and then apply their knowledge of each mode's operating logic to understand how they relate to each other. Only after this process has been performed can the pilot determine which modes are armed, and the method of auto-throttle engagement.

Previous research in the area of human automation interaction has indicated that operators of automation often have trouble tracking system operation, anticipating future actions, and understanding the reasons for the system taking the actions it did (Sarter & Woods, 1995; Woods et al., 1987). The result of these problems is that system operators, in the case of FMS, the pilots, can experience automation surprises. Automation surprises can be defined as events when “system behaviour violates operators expectations” (Sarter & Woods, 1997, p554).

To consider the situation from an SA perspective, tracking system operation and anticipating future actions can be considered comprehension and projection skills respectively. Because these skills constitute the higher levels of SA (Endsley, 1995b), it can be said that low SA of FMS status is linked to system operators experiencing automation surprises. Automation surprises are inherently undesirable as they are likely to result in deviations from the intended performance. In situations where accurate performance is critical there may be little opportunity to recover from inappropriate automation actions.

1.7 Level Of Automation

Another implication of the autopilot, auto-throttle and FMC combination is the various Levels Of Automation (LOA) in which the FMS can be operated. This complicates the monitoring task the pilot must perform to track system operation, by requiring the pilot to maintain an appreciation of the LOA that is currently in use. When the FMC is controlling the aircraft the LOA is at its highest (Endsley & Kaber, 1999) and the aircraft can fly the programmed flight plan essentially without any further human instructions. However, if a mode reversion occurs, the autopilot mode that takes over will only maintain the performance parameter that existed at the time of the mode reversion, such as a rate of descent. Therefore the aircraft is no longer being positively commanded to maintain the desired flight profile. In the case of a vertical navigation mode change, considerable pilot action would then be required to ensure the aircraft does not violate an altitude restriction or performance limitation. If the pilot is not aware of the change in LOA, the impact on the expected behavior of the system may not be realised until the intended flight target has been exceeded.

This study sets out to evaluate the SA commercial pilots have of FMS status, and the factors affecting its development. More specifically to explore the SA pilots possess of FMS, and the association between SA, motivation and operator experience.

CHAPTER 2: LITERATURE REVIEW

The new monitoring demands created by flight deck automation, and the negative consequences of automation surprises, have heightened the need for the pilot to have good global SA. As alluded to earlier, to gain an adequate understanding, or awareness, of the environment requires several processes to occur. The examples provided thus far indicate that some of the problems leading to an understanding gap relate to the attention that the pilot allocates to the system. This implies an element of appropriate motivation to generate a desire to perform well, and pay attention to the system and the environment in general. The following discussion and review of literature delves deeper into these concepts, examining each in depth. First, and most significant to this discussion is the need to define the nature of Situation Awareness (SA).

2.1 Situation Awareness

The term SA is a seemingly simple concept to describe whether or not a person knows what is going on around them. In fact, because of its apparent simplicity it has become a fashionable catch phrase used by professionals and non-professionals in many domains, including aviation (Wiener, 1993). Unfortunately, while a universally accepted definition for SA remains illusive, widespread use of the term only muddies the waters regarding the true nature of SA (Endsley, 1995b; Sarter & Woods, 1991).

To describe what most people mean when referring to SA there are some basic elements that are implied. Generally, when stating that an individual has good or bad SA it is meant that they understand what is happening in the surrounding environment. To reach this understanding some fundamental steps must occur. Firstly, to be aware of a situation the objects in the environment must be observed. Without knowing what is in the environment it is impossible to gain an understanding of what is occurring in that environment. Secondly, it is no good to simply know the physical attributes of environmental objects, such as size, colour and position, in isolation. To truly understand the situation they must be integrated into an overall picture of the scene (Endsley, 1995b). In most cases this mental representation of a situation is what people refer to as SA.

However, it would seem unlikely that SA is as simple as a mental picture that mirrors the external environment. Assuming that this proposition were correct, then in a dynamic environment in which elements are continually changing over time, SA would be equivalent to running an internal three dimensional simulation that emulates the real world. Research has shown that manipulating an internal world representation consumes considerable cognitive resources, and is a skill that remains relatively stable over time (Artez, 1991). Therefore, if an individual's SA rests upon their ability to manipulate an internal representation of the external environment, that person's SA is unlikely to show much improvement with experience. This is contrary to what is observed (Dingus et al., 1997; Endsley & Bolstad, 1994), and what each of us experience, as more experience is acquired at performing a particular task. The apparent ease with which an experienced pilot can handle the demands on his/her attention during a complex arrival procedure, in contrast to a newly qualified pilot, is a good example of the difference experience can make. This brings to light two intuitively apparent aspects of SA; 1) SA is affected by the amount of exposure to an environment, and 2) only exposure to the relevant environment contributes significantly to achieving high levels of SA in that environment. This implies that SA somehow incorporates application of very domain specific knowledge to the current situation, which is a concept that will be developed further in a later section.

In addition to these two points, the ability of an experienced pilot to allocate attention efficiently to maintain awareness implies a further element of SA. Considering that the same environmental stimuli are available to both the experienced and newly qualified pilot, what then makes the difference between the two? It would appear that experienced pilots have acquired a superior ability to anticipate demands and allocate attention to only those elements in the environment that are important to the task at hand. To be able to filter the important information from the abundant flow of sensory stimulus presented by the environment, a well-defined set of objectives, or goals, need to be used. By appropriately prioritising the current goals, as there are likely to be several goals operating simultaneously (Adams, Tenney, & Pew, 1995), it is possible to identify the environmental elements that will affect successful completion of the overall objective. In this way only a manageable subset of environmental stimulus needs to be considered, as opposed to the entire environment, which easily outstrips human abilities to process (Fracker, 1989; Gaba, Howard, & Small, 1995).

Trying to incorporate all of these elements into a single concept of SA, it becomes clear that SA must be more than a simple mental picture of the real world.

Does Situation Awareness Really Exist?

Another approach to defining SA has been taken by Sarter and Woods (1991). They started from the position that SA maybe no more than a collection of known cognitive process. In this way they tried to establish whether SA is actually a distinct phenomenon, or simply new jargon built up around the misinterpretation of integrated cognitive processes (Sarter & Woods, 1991). In summarising their discussion Sarter and Woods state that, "it seems justified to think of situation awareness as a distinct and unique phenomenon. It refers to the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments" (Sarter & Woods, 1991, p52). The significant element from this discussion that identifies SA as a unique phenomenon is the requirement to continually reassess the situation. SA is not gained instantaneously by simply viewing a scene; it is developed over a period of time as the situation unfolds (Endsley, 1995b). Without reassessing the environment, an individual's understanding of that environment loses its relevance as time passes. If this occurs, the person will be left with an "out-of-date" assessment on which future decisions will be based. As a result they will probably have trouble interacting with the environment. This often results in the operator feeling that they are falling behind the situation, or as sometimes described in aviation, the pilot ends up trying to "fly the aeroplane from the tail" ¹. Obviously, only an up-to-date understanding of the situation, or in other words current SA, is useful when trying to interact with the environment. Hence, the properties that define SA as a unique process are that it is an extremely perishable, time dependent phenomenon (Harwood, Barnett, & Wickens, 1988; Sarter & Woods, 1991).

It is now possible to say that in talking about SA, we are talking about a discrete phenomenon that involves spatial, temporal and goal elements. To understand SA in a commercial aviation environment, as intended in this study, it is necessary to adopt a definition for SA that can be applied to commercial operations.

¹ The phrase "flying the aircraft from the tail" is some times used by pilots to describe the feeling that they could not keep up with the aircraft in flight, and as a result felt like they were trying to fly while hanging on to the tail of the aeroplane.

Definitions

The literature provides a variety of definitions that attempt to describe SA and its underlying processes. Despite this variety there are some elements common to many of the definitions identified, these include perceiving environmental cues, comprehending the importance of goals and anticipating future needs (Selcon et al., 1991). The following examples illustrate different approaches to defining SA that incorporate these common elements:

- 1) *“SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1995b, p36).*
- 2) *“The definition of SA adopted by the headquarters of the Air Force was a pilot’s continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission and the ability to forecast and then execute tasks based on that perception” (Carretta et al., 1996, p22).*
- 3) *“The knowledge available to the pilot on critical matters such as the overall tactical situation, his own mission profile, weapons status, the positions and objectives of friendly aircraft, disposition and apparent objectives of hostile flights, presence of threats, refuelling rendezvous and other mission data” (Stein, 1986, p113).*
- 4) *“...SA has four basic components: 1) exceptional sensitivity to performance-critical cues in the flight environment; 2) a remarkable cognisance of the total combat situation; 3) the capacity to predict or anticipate changes in aircraft system states and operational conditions; and, 4) the ability to make valid and anticipatory rather than reactive decisions under conditions of time urgency and stress.” (Secrist & Hartman, 1993, p885).*

All these definitions contain very similar elements and, except for the first definition provided by Endsley, are very domain specific. This in turn limits their use to the arena for which they were developed (i.e. the domain of aerial combat), and any ability to compare SA demands across disciplines is diminished. To avoid this limitation a generic platform on which domain specific SA demands can be structured in a common way is required. For this reason the most appropriate definition identified in the

literature is that provided by Endsley, which has been adopted for this study. The definition of SA provided by Endsley (1995b) incorporates spatial, temporal and goal oriented elements in a form broad enough to be applied to any dynamic domain.

Situation Awareness vs. Decision-making

The definitions of SA provided by Carretta et al. (1996) and Secrist et al. (1993) also include decision making as part of the SA process. While it is acknowledged that SA makes an important contribution to the decision-making process, the steps required to reach a decision go beyond the process of achieving SA (Adams et al., 1995; Endsley, 1990b; Endsley, 1995b; Gaba et al., 1995). However, the dividing line between SA and decision-making is often not easily defined. Where exactly does the process of understanding the environment stop, and the steps toward reaching a decision commence? This dividing line becomes particularly blurred when experienced operators employ highly developed scripts that determine what actions should be taken. A script contains a set of instructions that determine what actions are required, based on actions that have proven successful in previous encounters of the same, or similar, situations (Endsley, 1995b). Once the current situation is matched to the prototypical scenario for the script, that script is activated. Triggering a script causes the actions it contains to be executed, in effect circumventing the need to consciously deliberate over a decision and allowing extremely fast recognition – action chains to occur. This blurred line between SA and decision-making is apparent in recent Naturalistic Decision Making (NDM) research. Current shifts in research on decision-making recognises that decisions in the real world are made in stimulus-rich environments with multiple feedback loops. “NDM broadens the focus of decision-making research from the decision event to the larger process of situation assessment” (Cannon-Bower, Salas, & Pruitt, 1996, p196).

Recognition Primed Decision-Making (RPD) is a model that incorporates this trend in decision-making research (Klein, 1993). The RPD model “describes how decision makers can rely on their experience to recognise situations and identify viable courses of action without comparing the relative benefits or liabilities of multiple courses of action” (Kaempf, Klein, Thordsen, & Wolf, 1996, p220). In other words, in complex situations the decision maker will select a viable course of action, then subject that selection to a mental simulation to evaluate its suitability. If the selected course of action is found to be unsuitable, the process is repeated until a viable option is found.

This process does not take into consideration whether one option is better than another, merely that a course of action will succeed (Kaempf et al., 1996).

To perform these simulations, in addition to accurate SA, a considerable amount of knowledge regarding the way environmental elements interact is required. This is the point where the SA process and the decision-making process begin to diverge. Good SA, as discussed so far, requires an understanding of the environment, and as an implication of that understanding must allow for anticipation of future events. However, evaluating the suitability of possible options through mental simulation goes beyond the construct of understanding what is occurring in the environment. To evaluate alternatives the individual must be able to re-run a scenario after changing certain elements to determine the impact of those changes. In this respect the decision event is dependent on, but also separate from SA.

An additional characteristic of decision-making that distinguishes it from SA is that a decision event can introduce an element of imagination and improvisation that would not be available from attaining high levels of SA alone. The crew's actions on board a DC10 that suffered a virtually complete loss of aerodynamic flight controls is a good example of improvisation based on good SA. In this incident the crew successfully controlled the aircraft after suffering the catastrophic loss of all three aircraft hydraulic systems. To achieve control over the aircraft the crew used differential engine thrust to affect changes in the aircraft's pitch and roll attitude (Kanki & Palmer, 1993; NTSB, 1990). This represents a novel application of a known undesirable aircraft attribute to achieve the ultimate objective, which is to achieve control over the aircraft's flight path.

Therefore, SA can be considered the platform from which decision events can be launched. If the platform is substantially complete and stable, the likelihood of a good result is significantly increased. Figure 3, taken from Endsley (1995b), presents a pictorial model that includes the relationship between SA, decision-making and the performance of actions. As can be seen from this model the understanding generated from the SA process feeds into the decision event, which in turn determines the actions performed. Each stage represents a distinct process that affects those processes downstream, but can still be considered separate from each other. It is also important to note that there are other elements external to the SA and decision making processes that

directly affect the performance of the system at each stage. These elements can be separated into two distinct categories: 1) task/system factors, and 2) individual factors. This demonstrates how the unique properties of a system, and the specific knowledge and expectations possessed by the individual contribute to SA, decision making and performance of action in dynamic environments.

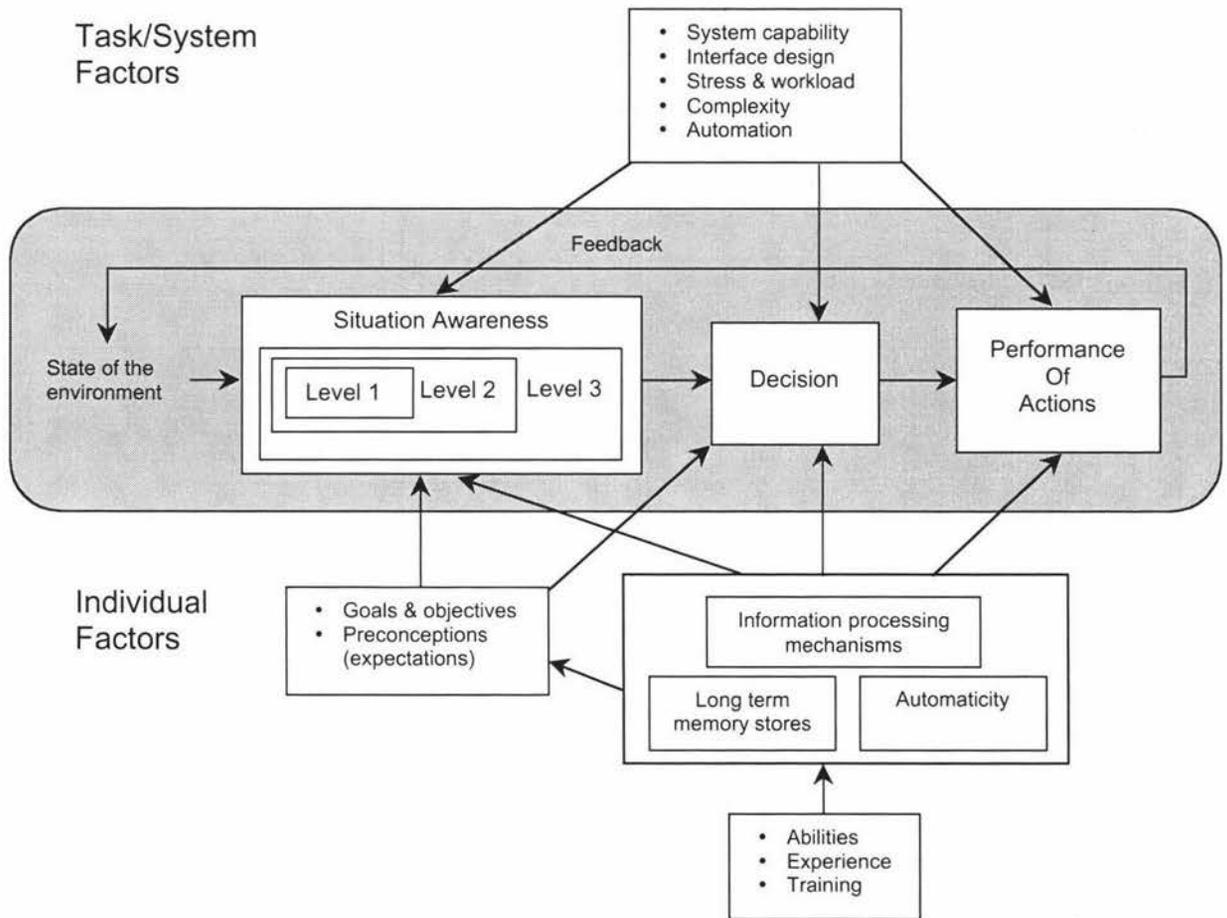


Figure 3: Model of situation awareness in dynamic decision making

Source: Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors*, 37(1), p35.

2.1.1 The Levels of Situation Awareness

The following section provides an overview of SA theory (for a detailed discussion see Endsley 1995b). Endsley states: “SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1995b, p36). In this

definition Endsley has identified three levels of SA: perception, comprehension and projection.

Level 1: Perception

To develop an awareness of any situation it is first necessary to perceive the relevant elements in the environment. This does not mean that all environmental factors must be processed to the same extent, but that the status, attributes and dynamics of elements relevant to the operator's current task are perceived. For a commercial pilot, these elements would range from the size, colour and position of cockpit indicator lights, to aircraft position/configuration, position of conflicting traffic and significant terrain.

Level 2: Comprehension

Once the relevant elements from the environment have been perceived they must be combined to form an understanding of the situation. However, it is not enough that the elements can merely be integrated to form an overall picture of the environment. Level 2 SA requires that the significance of this picture be understood in relation to operational goals. Therefore the operator must be able to identify patterns of Level 1 elements that represent a situation that might be significant with regard to achieving operational objectives. For example, if the pilot knows the position of other aircraft and geographical features around an airport, it is possible to draw a conclusion about the traffic plan the air traffic controller is implementing. This information is important when the pilot's goal is to land the aircraft.

Level 3: Projection

The highest level of SA is demonstrated by the ability to project the status of environmental elements in the near future. The projection of future environmental states may only take the form of a short-term forecast, but it is a vital prerequisite to achieving proficient performance. Level 3 SA makes it possible to anticipate future demands, and therefore, allows the operator to prepare themselves and their systems to handle those impending demands. It is important to note that Level 3 SA can only be achieved once Level 1 and Level 2 processes have been successfully completed. For the pilot who's objective is to perform a landing, once the traffic pattern has been established, it is possible to anticipate the arrival procedure the air traffic controller will issue to reach

the landing runway. This allows conformation of the current flight profile, or calculation of a new arrival procedure and profile to fit the situation.

2.1.2 Domain Specific

Even though the SA framework defined by Endsley is broad enough to apply to any domain, the specific elements important to a particular domain will always be unique. This is particularly true at Level 1 of the SA process (Endsley, 1995b). To complete the first Level in the SA process all of the environmental elements relevant to the operator's task must be perceived. While this concept can be applied to any domain, the elements in each domain that need to be perceived will necessarily be different. For example, the elements relevant for a pilot to perceive will be very different to those relevant to an air traffic controller. This is true even though the pilot and air traffic controller share the similar objective of understanding the current position of aircraft in relation to each other, and in relation to significant geographical features such as airports. Therefore, while the definition used here provides a common methodology to approach the SA requirements in any domain, the exact demands of each domain must be uniquely identified.

2.1.3 Attention Allocation

SA is a goal driven phenomenon, which allows attention to be allocated appropriately to elements in the environment. The consequence of attention allocation is that only a sub-group of environmental stimuli are observed, and that that sub-group is determined by the current objective. However, an overall appreciation for most, if not all, parameters relevant to the task outside this sub-group needs to be maintained. If this is not done the operator may miss important information that requires alteration of the current goal to achieve the overall objective (Endsley, 1995b; Sarter, 1995). For example while on final approach a pilot's current goal is to land the aircraft safely. To achieve this the pilot will be focused on maintaining the correct runway alignment, descent profile and airspeed. Attention will primarily be directed to maintain SA of flight parameters such as airspeed, altitude, rate of descent, heading, track and power setting to develop Level 3 SA of progress along the approach path. However, it is also vital that the pilot's SA continue to include elements pertaining to aircraft configuration. Failure to do so may

result in flying the perfect approach, but landing with the landing gear in the up position, which will fail to achieve the overall objective of landing safely.

In most cases an appreciation for parameters outside those that are vital to achieving the current objective will take the form of a trigger threshold. For instance, if a parameter is observed passing a threshold level this signifies a new event that demands closer attention, and may ultimately result in changing the current goal. Thus while achieving SA does not require detailed observation of all environmental elements, some level of awareness of the majority of environmental elements relevant to the task is required to ensure the overall objective is successfully completed. The tendency to focus on only a small subset of elements at the expense of the greater situation is also known as Cognitive Tunnelling (Woods et al., 1987). To avoid this undesirable event, it is important that the operator maintain a scan that incorporates all potentially important parameters relevant to the current situation.

2.1.4 Situation Awareness Errors

Due to the sequential nature of the SA process it is very difficult to reach a higher level of SA without first performing the preceding stages (Endsley, 1995b). As each level in the SA process builds on the output of the preceding level, failure to successfully perform any one of the three SA stages will result in less than optimal awareness. As a consequence of inaccurate SA the chances of performing accurately or consistently are markedly reduced.

If a total failure to complete a stage of the SA process occurs the breakdown will probably be obvious to the individual, and more than likely, they will be aware that they do not fully understand the situation. As a result it may be possible for the individual to apply appropriate coping strategies to minimise the negative consequences of their incomplete SA. However, if the failure at one of the SA stages is more subtle, and does not result in total failure to generate a reasonable output, the impact can be more significant. For instance, failure to read a value from an instrument correctly, without noticing the inaccurate reading, may corrupt the entire understanding based on that information. The reading will be of the appropriate type for the situation (i.e. an altitude), and therefore will allow integration and projection of the situation to take

place. However, because the actual value of the element being represented is incorrect, any resulting integration and projection will also be flawed.

Table 1 shows the underlying reasons why a failure could occur at any particular stage of the SA process.

Table 1: Errors in the SA process

<i>Failure to Perceive</i>
No data available Data difficult to detect Failure to scan data Misinterpretation Memory failure
<i>Failure to Comprehend</i>
Poor mental model Use of incorrect model Over-reliance on model defaults Memory failure Other
<i>Failure to Project</i>
Poor mental model Other

Source: Endsley, M. R., & Bolstad, C. A. (1994). Individual differences in pilot situation awareness. *The International Journal of Aviation Psychology*, 4(3), p288.

Most of these elements focus on failure in the individuals processing. However, while there are certainly individual abilities that help a person achieve SA, the support provided by the system can also be significant. The more tailored the information displays are to the operators needs, the easier it will be for them to achieve comprehensive Level 1 SA, and as a result they are likely to achieve better overall SA (Endsley, 1995b). Consequently their chances of good performance will also increase. Developing this concept further, if the system can provide the operator with information that has already been integrated, the operator's workload will decrease as a result. The decreased workload will free working memory resources that would have previously been consumed trying to maintain level 2 SA. As a result the operator will be able to dedicate more working memory capacity to other functions such as strategic decision-making. This reflects a human-centred design approach that has become the accepted

practice for design of machine agents in complex dynamic environments (Billings, 1991a; Billings, 1991b; Gerhardt-Powals, 1996; Wiener & Curry, 1980; Woods et al., 1997).

Obviously human-machine interaction is a team effort, and as improvements in system design occur, individuals should also try to improve their own SA abilities. By improving knowledge of system operation, and increasing understanding of the interaction between environmental elements, an improvement in SA abilities is likely (Degani, Shafto, & Kirlik, 1999; Rasmussen, 1986). It is important that such knowledge be acquired in a way that situation relevant information can be recalled and applied when required. This requirement leads to the notion that experience is one of the factors affecting SA. However, before reviewing the research dealing with the effect that experience has on SA, the possible methods for evaluating SA will be considered.

2.2 Measuring Situation Awareness

Quantitatively measuring how well each level of the SA process is being performed is not an easy prospect considering the cognitive nature of SA. It is not possible to look inside a person's head to observe what they are thinking at any point in time, nor what factors they considered to arrive at a decision. Despite our inability to see inside a person's thought processes, it is possible to make some inferences regarding cognitive function from their actions and responses to queries. In this way we can begin to form an understanding of the elements that impinge on a particular thought process. Many techniques have been used to probe human thought processes, ranging from performance measures to batteries of questions, with varying successes. Each of these techniques has been applied to the dilemma of measuring SA in dynamic domains, with mixed results, the pros and cons of which are discussed below.

2.2.1 Performance Measures

Performance measures try to evaluate SA by measuring an operator's proficiency during task performance, and making inferences about their knowledge of the situation from their actions. These techniques involve procedures such as removing items from a display and measuring the time taken for the operator to notice, or measuring deviations from a stated performance target (Endsley, 1995a; Sarter & Woods, 1991). In both cases

it is possible to draw some conclusions about the operator's awareness of the elements involved, however, an equal number of assumptions must also be made to reach those conclusions. In the first case mentioned, if the operator takes an action due to the changed information it is obvious that they must have perceived the change and realised its significance. However, if no action is taken, or action is taken a considerable time after the change occurred, this does not always mean that the change was not perceived and accounted for earlier. In some cases the operator may have perceived the changed state, but not considered it a high priority and therefore not taken action until other higher priority tasks had been completed. Alternatively, the operator may have been aware of the change immediately, but decided to wait and see if the change was significant, or merely a false alarm (Endsley, 1995a). In either case, while the researcher could not observe the individual's decision that no action was required, the individual would still have been aware of the event. This problem reflects the division between the SA process and the resulting performance. Due to these problems, performance measures are less than adequate to tap the level of SA an operator has at any point in time.

2.2.2 Subjective Measures

Self-Reporting

Self-reports of an individual's own SA are easy and cost effective to obtain, but the information generated is likely to be subjective and inconsistent. This technique requires an individual to make an estimation of his or her own level of SA during, or after, task execution. Another factor of significance is that self-reported SA evaluation techniques have not proven effective in revealing much about the higher-level knowledge structures associated with SA (Selcon et al., 1991). For the very reason that it is not feasible to expect someone to know that they do not know something, it is not a realistic proposition for someone to know their SA is incomplete (Endsley, 1990a). In effect, this is what self-reported measures of SA ask a person to gauge. By asking an individual to estimate their own level of SA, they would have to estimate how much of the environment they understood in comparison with the extent to which they should have understood the environment. Obviously, this cannot be done without first knowing what constitutes perfect SA. However, if the individual knew this they would probably have perfect SA. Consequently, if a person's SA is approximately 65% correct they are

not likely to know that they are missing 35% of the situation, and will assume that what they know is sufficient. This could lead an individual to rate their SA as good, even though someone else with the same level of SA but a better appreciation for the gaps in their knowledge might rate themselves as having average SA. To compensate for the problem that someone cannot have SA regarding something they are unaware of, the individual will mostly likely fall back on their performance to gauge their SA. This will result in an individual rating their SA as high when task performance was good, and conversely rating their SA as low when task performance is substandard. In light of these problems self-reported measures of SA generally reflect the individuals perception of their performance and confidence in their SA (Endsley, 1995a), rather than their actual awareness of the environment.

In some cases expert operators may be able to tell that their SA is incomplete if information deemed necessary in their mental model is missing. By judging the amount of missing information the expert operator may be able to estimate their level of SA reasonably accurately. Apart from being able to report SA more accurately, this ability to gauge the weaknesses in SA has a much more practical application. It will allow the expert to employ appropriate strategies that takes into consideration the weaknesses in their SA minimising the chances of a negative outcome due to poor SA.

Verbalisation

Another way to try and tap into an individual's thought process is to require them to verbalise the cognitive steps they take while performing the task. By analysing the transcript taken during task execution, it is possible to generate a model of the factors that contributed to the individual's decisions and actions. However, the requirement for an operator to verbalise all the elements they consider during task execution imposes an additional workload on the individual. This additional task may result in excessive workload for the operator if the primary task already imposes high cognitive demands (Endsley, 1995a). As a consequence the individual may simple be unable to perform their normal tasks and the verbalisation task at the same time. In which case the content of the verbal reports could suffer, or attention may be diverted from the primary task to the artificial task of reporting their cognitive processes. In either case SA results would not reflect the true nature of the operator's SA in the real environment.

Another problem faced by the operator during a verbalisation procedure is the limited time that might be available to report each step considered. This becomes particularly troublesome if well developed schemata are involved that incorporate a significant amount of domain specific knowledge. The operator may not consciously take each step required to reach the awareness they have and only report the resulting knowledge. Alternatively, the operator may not see the need to explain each step of their thought process, as they may assume certain aspects are fundamental and known by all. This can make interpreting information reported during a verbalisation exercise problematic (Endsley, 1995a).

Verbal reporting therefore tends to be very intrusive on performance of the primary task, and is likely to result in considerable interference that will affect the accuracy of SA information gathered.

Observer Rating

Observer rating involves a neutral individual evaluating the participant's SA as they perform the task. In some cases the observer is given a legitimate position in the task such as a co-pilot or air traffic controller (Sarter & Woods, 1991). The observer's objective is to rate the participant's SA on the observations they can make of the participant's actions augmented by any incidental verbal reports. However, as with performance measures it is extremely difficult to determine whether an action is associated with an event, and therefore, what it indicates about the individual's SA. If the observer takes the position of a legitimate crew member, they can use their position to probe the participant's knowledge. While this may clarify whether or not the participant has perceived certain elements, it also runs the risk of directing the participant's attention toward elements mentioned by the observer. As a result there is a high risk that the participant's SA will be biased toward the observer's line of questioning. The intrusiveness of this technique on primary task performance is considerable, and consequently may affect SA accordingly. Again the participant's SA is likely to be very different from the level of SA they would normally have in the real environment. An additional point to note is the difficulty in obtaining information on the higher levels of SA using this technique, which can only be achieved via inference.

Post Test Questionnaire

By administering a questionnaire after the task has been completed there will be no interference with task execution, or possibility of artificially directing the individuals SA. The significant draw back with this technique is the quality of the information gained after completing a task. Human memory recall of detail for past events is not good, even for relatively recent events. In the main, recall of events is affected by the time elapsed since the event, and influenced by events that occurred between the administration of the questionnaire and the associated event during the task (Nisbett & Wilson, 1977). Due to this, it is likely that recall of events that occurred early on in a task will be vague or forgotten altogether. Therefore, administering a questionnaire after the task has been completed is likely to only provide an accurate idea of the individuals SA at the end of the task (Endsley, 1995a).

Post Hoc questionnaires can also suffer from performance bias similar to self-reporting techniques. As mentioned human recall for the exact detail of past events is not accurate, consequently this may lead the person to reconstruct what they believe their SA was at the time. This will occur in lieu of recalling what actually took place as that information might not be available from memory. In the absence of being able to recall the actual answers, the individual will reconstruct what they believed to have happened, which will be influenced by their performance in that area. Therefore, the results from this technique is also likely to reflect the individual's perceived performance rather than their SA (Endsley, 1995a).

Freeze Technique

While post hoc questionnaires may have limitations, a well-designed set of queries can capture valuable information regarding an individual's knowledge of a situation at designated points during the task. To take advantage of the information that can be gained through questioning, a technique has developed that involves freezing a simulated task during mission execution. This technique requires a participant to perform a simulation of the task being evaluated, during which the simulation will be stopped so that questions about the situation in the simulation can be administered. The answers given to the queries administered during simulation freezes provide a relatively accurate snapshot of the individual's SA at the time of the simulation freeze. These

results can then be evaluated individually, or averaged over the entire session to gain an impression of the individual's overall level of SA.

The technique of freezing a simulated task is not without its pitfalls however, and the ability of this method to effectively measure SA will be compromised if the questions prompt the participant to artificially direct their attention toward a particular aspect of the task (Endsley, 1995a). Questions that continually ask for information that pertains to only one area of a task will cause the participant to direct more of their attention to that area than they normally would. While directing more attention to the area being queried may result in a high percentage of questions answered correctly, it will also mean that the results will not reflect the individual's normal SA of the environment. Due to the redirection of attention it is also likely that participant's SA of other areas of the task will suffer. Consequently, even though high SA may be measured for the area being queried, this may not reflect the participants overall SA (Endsley, 1995a). Therefore, false assumptions regarding overall SA could result if the score from the localised area measured is generalised to the task as a whole. Consequently care needs to be exercised to avoid cueing the participant to specific areas of interest to the researcher.

The design of a simulation freeze technique may give rise to another potential SA bias if the participants can predict the freeze points chosen to administer SA queries. If the simulation is always stopped after a certain event, or at predictable intervals, it is likely that the participants will learn the pattern and use this ability to temporarily increase their scan rate, and therefore SA, just before a freeze occurs (Endsley, 1995a). If the participant can achieve this it is likely they will correctly answer a higher percentage of queries, artificially inflating their SA above the level that is normal for task execution. The freeze technique will also suffer if the intrusiveness of stopping the simulation during execution of the primary task affects the participant's ability to resume operation when the simulation is re-started. If operators experience trouble resuming a task after being interrupted, it is likely that their SA will suffer as a result. However, despite the drawbacks that could result from interrupting a task to administer SA question, this technique provides the most promise as a reliable, quantitative means to measure SA.

2.2.3 SAGAT Procedure

Overview

The Situation Awareness Global Assessment Technique (SAGAT) is a freeze technique developed by Endsley (1995a) to evaluate operator SA in dynamic environments. Endsley (1995a) performed two studies to evaluate the effectiveness with which SAGAT measured operator SA, and whether the technique was unduly intrusive. The first study was designed to determine how long into a freeze SA information could be reliably recalled by participants. Results of this study showed that subjects could recall SA information accurately for up to 5 minutes after a simulation freeze. The second study was designed to evaluate whether freezing the simulation caused participants to alter their behaviour after the simulation was resumed. In effect this study was designed to evaluate how intrusive the freeze technique is on task execution. Endsley found that the simulation freezes did not unduly intrude on the participant's execution of their primary task, and participants "were able to readily pick up the simulation at the point at which they left off at the time of the freeze, sometimes with the same sentence they had started before the stop" (Endsley, 1995a, p76). Even though these studies demonstrate that participants could recall information up to 5 or 6 minutes after a freeze with little decay, freezes of 2 minutes were considered optimum when intending to resume the simulation. In addition, it was found that no simulation freeze should occur in the first 3 minutes of the task to allow participants to establish their SA, and for the same reason, no 2 freezes should be closer than 1 minute apart. The maximum number of stops that can be made in one session before simulation freezes begin to affect participant performance was not established outright. However, Endsley did not observe any detriment to SA when the simulation was paused as many as 3 times in a 15-minute period. Overall the results of these studies found that the SAGAT method did provide a valid objective measure of SA, and that it did not unduly interfere with task execution provided a few guidelines were followed (Endsley, 1995a).

To ensure that the participants are not prompted to direct their attention to certain areas of the environment that might be of interest to the researcher, it is important that the queries be designed to assess the Global situation. If a global approach is not used, and participant's attention is directed toward a particular line of questioning, the resulting SA measured would not be representative of their normal SA distribution. In this way the SAGAT technique requires that a delineation of the SA requirements for the specific

environment be made, which includes Levels 1, 2 and 3 of the SA process. Queries should aim to gather information on the participant's knowledge of system function and all relevant environmental elements pertaining to the task being undertaken. Designing the queries on a global basis minimises the likelihood that participants will be able to anticipate the questions they will be asked, and therefore nullify the possibility that they will be able to bias their SA toward a particular line of questioning. In addition, by sampling the participant's knowledge on a Global basis it is possible to determine if the participants are directing more of their attention to one part of the situation than others. By evaluating such tendencies it is possible to determine if the participants have been cued to observe certain elements in the environment, and the consequences of their biased SA.

While the Global query design can minimise the potential risk that participants' SA might be artificially directed, if the simulation freezes can be anticipated there is still a risk that the participants' SA results will not reflect their normal levels of awareness. If simulation freezes occur at predictable times during the simulation, such as just after a system change, it is likely that the participants will quickly learn this pattern. Once the participants are aware of the pattern they will most likely use that information to increase their scan rate just prior to a freeze, and thereby artificially increasing their SA. To overcome this problem the timing of simulation freezes, and the queries to be administered, should be randomly chosen. In addition, random selection of stop times and queries also maintains statistical consistency across testing sessions (Endsley, 1995a).

To promote the recall of valid situational information the design of SAGAT queries should be compatible with the participant's mental representations of the knowledge in question. Therefore, queries should be easy and intuitive for the participant to answer, preferably presenting information in a format with which they are familiar. By doing so it is more likely that the information held in applicable mental models will be triggered, and a true picture of the participant's SA related knowledge obtained. To further tap the information experienced operators possess in mental models, it is important for participants to respond to each question presented, even if they are not sure of the answer. Responses made in this way will provide information on the default values the

participant may have built up through experience, which make a valid contribution to SA.

Due to the fact that the SAGAT technique is attempting to capture the participant's internal knowledge of the situation, it is important that no simulation displays are visible during query administration. Obviously, if the participant can still see any of the simulation displays when answering the queries they will not have to rely on their memory of the simulation, but will read the information directly. This will certainly affect the resulting SA scores.

2.3 Experience

As previously mentioned, individuals with more experience operating in an environment are capable of achieving, and maintaining higher levels of SA (Dingus et al., 1997; Endsley & Bolstad, 1994). This implies that there must be a way to recall relevant previous experiences from long-term memory, and apply that experience to the current situation in a useful way. Such a process circumvents the limitations of working memory, which would rapidly become overloaded if it were the only resource used to achieve SA and handle all other cognitive demands required to operate in the environment. The problem of overload is particularly pronounced if the workload to achieve Level 2 and 3 SA is placed on working memory alone (Endsley, 1995b). To facilitate the recall of relevant previous events at the appropriate time, information stores in long-term memory must be well structured. The accepted term used to describe such memory structures is schemata (Endsley, 1987; Endsley, 1988; Fracker, 1988).

Schemata

Schemata provide frameworks to organise information from the environment into understandable events. "Schemata are conceptual abstractions that mediate between stimuli received by the sense organs and behavioural responses" (Cason, 1983, p439). Essentially, schemata contain the rules for grouping various elements in the environment, and define the associations between those groups of elements. In this way a schemata provides the context to understand the significance of a particular arrangement of environmental elements. In the absence of a schemata, the elements in the environment would appear as a series of unrelated facts that do not yield any

understanding of the situation in isolation, or logically lead to the development of a coherent picture of the situation.

It is important to note that schemata are abstractions, and as such contain little detail about specific examples of environmental states. However, as a consequence of their abstract nature schemata can be applied to any situation where the environmental elements approximate those held in the schemata. This is made possible by the fact that the schemata framework only contains generic descriptions of elements expected to be found in the environment (Endsley, 1995b). More specifically, a schema contains a set of rules that determines the class of objects that can take a particular slot, or be “bound” to the schema framework (Cason, 1983). However, these rules are not absolute, and elements can be bound to schemata as long as they possess some resemblance to the prototypical element. For example, one of the pilot’s objectives during a take-off is to keep the aircraft on the centre-line of the runway. This is normally achieved by comparing the white centre-line markings with the pilot’s own position. However, when taking off on a grass runway, or at night, the centre-line markings are not visible for the pilot to use as the centre line reference. In this case the pilot must use some other element that provides the same feedback to substitute for the missing centre-line. As such the substituted element must share similar properties to the missing centre-line, but it will not necessarily consist of white paint markings. In either case the same centre-line tracking schema can be applied to any take-off event to keep the aircraft straight on the take-off roll. To re-cap, a schema framework contains “slots” to which environmental elements may be assigned to provide the individual with a means to place those elements in the context of the overall situation. Combined with the superior human pattern matching abilities, these associations provide the individual with an efficient method to rapidly understand their environment (Endsley, 1995b).

Schemata can also contain sub-schemata that provide more detailed descriptions of constituent events. “Schema are also organised sequentially. Sub-schemata embedded in a schema may be ordered to represent changes over time or in location, cause-effect relationships, and sequencing of stages or actions in events” (Cason, 1983, p437). Therefore by activating a high level schema an understanding of an event can be gained without having to know the detail associated with a particular occurrence.

Mental Models

As a schemata for a particular situation or system becomes more refined it loses its generic nature, and its applicability becomes limited to the particular situation in which it has evolved. Such knowledge structures have evolved beyond the strict definition of schemata and more closely fit the concept of a mental model (Rouse & Morris, 1985). Endsley (1995b) points out that mental models can be considered specific instances of schemata applicable to a specific situation or system. Mental models contain more detailed classifications of objects in the environment and explanations about how the system functions than schemata. Consequently the individual will be able to gain a more precise understanding of the situation for which they have a mental model due to this additional detail.

To reach such intricate levels of refinement requires repeated exposures to a situation to allow the individual to observe the particular events that differentiate one scenario from another. In this way, experience becomes a significant factor contributing to the development of useful long-term knowledge stores.

Default Values

As mental models become more refined over time, more information is incorporated into the knowledge structure. After a particular value is observed to re-occur several times, it may be added to the mental model as a default value. Default values incorporated into a mental model provide the individual with a reasonable value to substitute for missing environmental information (Endsley, 1995b). This allows the individual to continue operating even though all the information they may need is not available from the environment. Examples of default values might be the speed at which a type of aircraft is known to travel, or a typical rate of descent on an approach.

Default values also serve another purpose of significant value to flight crews. Cross checking information is an essential element of piloting an aircraft, and good default values will assist a pilot assess the quality of information received. Comparison of actual environmental information and the mental model default value helps the pilot assess the reasonableness of the data they are viewing, and whether the situation “looks right”.

Schema Processing

Schema processing can operate in two directions, top-down and bottom-up (Cason, 1983; Endsley, 1995b). Top-down processing works by associating a particular schema to the current situation by understanding the higher-level objective. For instance, if the pilot knows that the current objective is to keep the aircraft on the runway centre-line during a take-off, then the schemata for this will be activated. As a result, the pilot will search out the environmental information that the schema determines important to achieve that goal. Alternatively, bottom-up processing triggers a schema by matching patterns of environmental elements to those contained in the schema. In the take-off scenario, the pilot may notice that the runway centre line begins to move left; in turn this cue may trigger the centre-line tracking schema. As a result of activating the schema the pilot has immediate access to the overall understanding associated with that situation. In this case the understanding is that the aircraft is drifting off centre-line and action is required to stop this trend from becoming worse. To work effectively both top-down and bottom-up processing need to occur simultaneously, and each requires the other (Cason, 1983). This provides a facility to judge whether or not the current objective is being achieved.

By selecting an objective and activating the appropriate schema top-down processing begins, at the same time environmental searches try to match patterns of elements to those found in a schemata. However, this type of expectation driven search technique can introduce an undesirable element. If only those environmental elements specified in the schemata are observed, it is possible that elements important to other schemata, and therefore objectives that are not currently active, will be missed. This opens the window for cognitive tunnelling and potentially reduces the likelihood that the overall objective will be achieved. Another consequence of expectation driven searches is that elements that are in disagreement with the current schemata are often rejected, rather than causing re-evaluation of the current schemata (Moiser, Skitka, Heers, & Burdick, 1998; Patrick, Gregov, Halliday, Handley, & O'Reilly, 1999). In some cases, rather than rejecting the environmental cue all together, it is rationalised as being in agreement with the current schemata, even though it is not (Degani et al., 1999). Either case will result in use of an inappropriate schema and as a consequence poor SA will probably result, potentially leading to substandard performance. While this discussion specifically dealt with

schemata processing, processing of mental models will operate in a similar fashion due to the fundamentally similar nature of the knowledge structure.

In summary, as more exposure to a particular environment is received, the rules contained within the schemata for that environment become more refined. Refinement of schemata leads to development of mental models, which makes finer discriminations and classifications of environmental situations possible, and can incorporate default values. In combination these abilities refine an individual's understanding of the situation and provide the ability to operate effectively with minimal information (Cason, 1983; Endsley, 1995b). This provides the experienced operator with a method to apply detailed relevant past experience to a situation in a very fast and efficient manner.

Automaticity

Experience generates another form of high speed processing to circumvent the bottleneck caused by working memory called automaticity. Automaticity is typified by fast action, normally operating below the level of conscious attention, and consuming very little cognitive resource. As a result automatic processing takes place without the individual having to consciously focus on the stimulus or the associated steps to reach the resulting action (Endsley, 1995b). An example is the ability of an experienced driver to effortlessly change gears in a manual car, or an experienced pilot's ability to accurately maintain airspeed. In both cases there are Level 1 SA elements present that immediately trigger the performance of an action, or impart a greater understanding about what is happening. Often when automatic processing occurs in this manner the individual will be able to accurately identify that there is a problem, or the need to perform an action, but will not be able to verbalise the reason why (Nisbett & Wilson, 1977).

Another indicator of automaticity is the individual's inability to recall the exact sequence of events that occurred during any single execution of a task that they perform on a regular basis. As described by Endsley (1995b) an example of this is a person's ability to drive a car home from work without incident along the same route they use every day, but not being able to recall exactly the events that occurred on any particular trip. Although automaticity occurs without conscious attention, it is still reasonable to think that it contributes to SA, which is a conscious function. Despite the fact that the

individual will not be able to articulate the cognitive steps that precipitated a particular action or conclusion, the process would still have been initiated from an assessment of Level 1 elements. Therefore, in effect automaticity operates in a similar fashion to highly developed mental models, in that patterns of environmental elements are matched to prototypical scenarios that contain information and action scripts built up through experience. This provides a single-step process to determine the action required from the stimulus available (Logan, 1988).

2.4 Motivation

It would be a rare event for human action not to be induced by some form of motivation. Whether it is a desire to achieve a personal goal, or to help someone else, there is usually an intrinsic need driving the action. Motivation refers to a set of processes that arouse, direct and maintain human behaviour toward attaining a goal (Baron & Greenberg, 1990). Motivational research has identified approximately 20 dynamic factors that contribute to adult motivation, which have been separated into Ergs (or drives) and Sentiments (Cattell, Horn, Sweney, & Radcliffe, 1959; Cattell & Miller, 1952).

Ergs

“In popular terms an erg is a drive or source of reactive energy (hence the term erg) directed toward a particular goal, such as fear, mating, assertiveness” (Cattell et al., 1959, p2). An Erg is considered to be an innate desire to act in response to emotional states caused by observing certain classes of elements, and tend to be a less rationalised drive. Not being rationalised, as sentiments are, erg factors are not developed through conscious processes. Instead ergs tend to reflect a reflex that arouses and directs behaviour toward a desired goal. Ergs therefore represent the unconscious element of motivation (Cattell et al., 1959).

The two ergs that will be considered further in this study are the Assertiveness, and Fear or Escape erg. As defined in the MAT handbook (Cattell et al., 1959) these ergs refer to:

- 1) Assertiveness Erg: This erg represents one of the fundamental drives for mastery, ambition and status seeking. It manifests itself in the desire to excel in competition, and to associate with high status groups.

- 2) Fear or Escape Erg: The goal of this erg is to maintain security by avoiding danger. In this respect the Fear erg reflects an individual's alertness to external dangers such as, accident, illness, loss of financial security and death, among others.

Ergic tension level, or the strength of an erg, is not considered to be constant over time but is hypothesised to be a function of;

- * Stimulation level in the environment.
- * Constitutional strength.
- * History of the drive (the impact of earlier exposures, fixation and deprivation).
- * Current physiological influences.
- * Degree of gratification (satisfaction).

Variations in any of the above factors will result in different ergic tension levels, and therefore, the individual will experience different levels of motivation (Cattell et al., 1959). Consequently, variations in the level of ergic tension will influence the energy an individual is willing to expend to satisfy the objective of the erg.

Sentiments

As opposed to ergs, which are considered innate drives, sentiments refer to patterns of motivation that are acquired through interaction with the environment and culture of the society. In other words, sentiments are developed over time and are modified by conscious attention to the environment in which the individual lives. Consequently a sentiment tends to reflect motivation drives acquired from the dominant culture. Due to the learnt nature of sentiments, they develop to differing degrees in different people, and reflect the individual's investment in certain cultural institutions such as career, home and country (Cattell et al., 1959). The stronger the sentiment, the greater the personal investment an individual is likely to make in the interests of attaining the object of that sentiment.

Only one sentiment will be considered in this study, which is the individual's level of interest in Career. Career sentiment reflects the degree of acquired interest an individual has in career progression.

As a result of an individual's current combined level of ergs and sentiments (or total motivation) they experience internal pressure compelling them toward specific goals or objectives. Consequently, this will affect an individual's allocation of attention, and the extent to which they are prepared to invest themselves in activities associated with the motivational objective.

2.5 Level of Automation

The level of automation available to perform a task impacts the number of elements that an individual must monitor to understand their environment. This monitoring task becomes even more challenging if the automated elements can autonomously change their level of authority. Addition of automation, especially those capable of different levels of authority, introduces new elements that the operator must account for in their SA process to effectively understand and project the status of the elements in the environment.

In the broadest sense automation refers to allocating the performance of a task, or part of a task, that was previously performed by a human operator to a machine agent (Billings, 1991a; Parasuraman & Riley, 1997). This definition can be applied to an enormous variety of functions, from the simple action of a thermostat to maintain temperature, to the complex operation of autonomous FMS. As an implication of the varying complexity of machine agents, the amount of interaction required between the human operator and the machine to utilise the devices also varies considerably. Operation of many modern machine agents is further complicated by the different modes in which the systems can function. These modes of operation normally determine the amount of the task that is turned over to the machine agent to control (Endsley & Kaber, 1999). In many systems the ability to operate in different modes is intended to provide the human operator with operational flexibility to cope with unforeseen circumstances, however, this can also lead to added operating complexity. In effect providing different modes of operation presents the human operator with various Levels of Automation (LOA) that can be engaged to perform a task. Therefore, to successfully complete the task and achieve the desired goal, the operator must maintain an awareness of the LOA that is engaged. Failure to do so would result in invalid assumptions being made with regard to the division of tasks between human and machine, and therefore

what actions the machine will or will not perform. As a result another monitoring demand has been created (Parasuraman, Bahri, Molly, & Singh, 1991).

To evaluate the effect of operating at different LOA's it is necessary to define how many Levels might exist, and the boundaries for each of these levels. Previous research into the significance of LOA on performance achieved this by classifying LOA according to the degree of human-machine interaction required to execute a task. Several elements of human-machine interaction have been identified as being common to most dynamic environments (Endsley, 1987; Endsley & Kaber, 1999; Sheridan & Verplanck, 1978).

Those elements are;

- 1) The level of feedback to the human operator the system considers necessary,
- 2) How the tasks are divided between the human operator and machine agent,
- 3) Which agent is responsible for option generation and selection, and
- 4) Which agent is responsible for implementing the selected action.

In this way a LOA taxonomy with 10 levels has been defined (Endsley & Kaber, 1999). In this taxonomy the levels of automation range from full manual control where the operator must perform all actions, to full automation where the operator merely watches the machine carry out the task. The full range of automation levels as described by Endsley and Kaber (1999) is as follows.

Manual Control

The human operator performs all tasks including monitoring the state of the system, generating performance options, selecting the option to perform (decision making) and physically implementing it. For example, piloting an aircraft without the use of any FMS assistance.

Action Support

At this level, the system assists the operator with performance of the selected action, although some human control actions are required. FBW aircraft flight control systems that use pilot input as the basis to set flight control surface position is an example.

Batch Processing

Although the human generates and selects the options to be performed, they are then turned over to the system to be carried out automatically. The automation is, therefore, primary in terms of physical implementation of the tasks. Flying an aircraft using basic autopilot modes, without reference to the FMC, is an example of batch processing.

Shared Control

Both the human and the computer generate possible decision options. The human still retains full control over the selection of which option to implement; however, carrying out the action is shared between the human and the system.

Decision Support

The computer generates a list of decision options that the human can select from or the operator may generate his or her own options. Once the human has selected an option, it is turned over to the computer to implement. This level is representative of many expert systems or decision support systems that provide option guidance, which the human operator may use or ignore in performing a task. This level is indicative of a decision support system that is capable of also carrying out tasks, while the previous level (shared control) is indicative one that is not.

Blended Decision Making

At this level, the computer generates a list of decision options that it selects from and carries out if the human consents. The human may approve of the computer's selected option or select from among those generated by the computer or the operator. The computer will then carry out the selected action. This level represents a higher level decision support system that is capable of selecting among alternatives as well as implementing the selected option.

Rigid System

This level is representative of a system that presents only a limited set of actions to the operator. The operator's role is to select from among this set. He or she may not generate any other options. This

system is, therefore, fairly rigid in allowing the operator little discretion over options. It will fully implement the selected action, however.

Automated Decision Making

At this level the system selects the best option to implement and carries out that action, based upon a list of alternatives it generates (augmented by alternatives suggested by the human operator). This system, therefore, automates decision-making in addition to the generation of options (as with decision support systems).

Supervisory Control

At this level the system generates options, selects the option to implement and carries out that action. The human mainly monitors the system and intervenes if necessary. Intervention places the human in the role of making a different option selection (from those generated by the computer or one generated by the operator), thus, effectively shifting to the decision support LOA. This level represents the highest LOA provided by current commercial aircraft FMS, when the FMC is given authority to control the autopilot.

Full Automation

At this level the system carries out all action. The human is completely out of the control loop and cannot intervene. This level is representative of a fully automated system where human processing is not deemed to be necessary. (Endsley & Kaber, 1999, p464)

This taxonomy is sufficiently generic to apply to most domains involving real time control of machine agents. By using these LOA definitions it is possible to consistently evaluate the variability of SA and performance at various levels of automation assistance or control (Endsley & Kaber, 1999).

2.6 Effect of Experience on Situation Awareness

As each individual will probably be aware through personal experience, and the evidence provided by research performed to date, there is a beneficial impact on a person's ability to operate in an environment due to that person's previous experiences

(Dingus et al., 1997; Endsley & Bolstad, 1994). Increasing the amount of exposure to an environment allows an individual to reinforce their schemata and refine mental models so they are more applicable to the systems in question. This refinement process increases an individual's ability to attain and maintain SA in the environment.

Effect of Schemata and Mental Models on Situation Awareness

Schemata, and the more detailed mental models, promote better SA by providing an invaluable resource to circumvent the limitations of human working memory. Working memory is only capable of handling a few pieces of information at a time while performing transformations on that information (Svensson, Angelborg-Thanderz, Sjoberg, & Olsson, 1997; Weinstein & Wickens, 1992; Zhang, 1997). By avoiding this limitation, an individual can cope with the flow of information present in complex dynamic environments.

Mental models achieve this by providing a mechanism, established through experience, which allows an individual to ascribe meaning to a situation by matching environmental patterns to those held in the model. Understanding, contributing to SA, is gained when environmental elements can be grouped into coherent patterns and given context in relation to other elements, or groups of elements. Mental models effectively achieve this in one step, moving from pattern matching directly to comprehension as a result of refinement through past experience. As a result, the individual has access to a fast efficient process to achieve high levels of SA without taxing working memory (Endsley, 1995b). This has many benefits as the reduced working memory load allows more resources to be allocated to strategic planning and decision-making processes.

Another potentially positive spin-off from the ability to make rapid efficient situation assessments arises from the processing speed. Being able to integrate environmental elements into the SA process quickly promotes a higher scan rate, allowing the individual to move from one set of elements to the next more frequently. This reduces the tendency for the individual to spend a disproportionate amount of time trying to understand one group of sub-goal elements at the expense of the situation as a whole, thereby avoiding the tendency to be drawn into cognitive tunnelling. Therefore, faster situation assessments facilitated by well-developed mental models allows an individual

to distribute their attention more evenly over the environment, and as a result they are likely to achieve better global SA.

Benefits Of Dual Processing

The parallel bottom-up and top-down processing that is inherent in schemata and mental models also benefits an individual's SA process. While top-down processing drives information searches toward appropriate goals, at the same time bottom-up processes provide feedback on the degree to which those goals are being achieved (Cason, 1983; Endsley, 1995b). Such feedback loops are vital considering that SA is a time dependent phenomenon and rapidly loses its relevance if not continually updated (Harwood et al., 1988). Without monitoring feedback on the achievement of operational goals, the individual's understanding of the state of the environment will rapidly lose its context. If the operator becomes removed from the environment in this way, it is likely that their SA will suffer as a result (Sarter & Woods, 1991).

Limitations of Mental Models

Despite the processing benefits of mental models, there are pitfalls for the experienced operator when using highly developed mental models in commonly encountered, or routine, situations (Endsley, 1995b). The danger here can arise from the narrow information search defined by the dominant mental model for the situation. Combined with complacency regarding the familiarity of events, efforts to attend to a wider scope of environmental elements may not be made. In these cases the individual will seek out the information that the mental model defines as important to achieving the goal, and in many cases, not attend to any other potentially significant cues. This is a particular problem in modern glass cockpit aircraft, and the pilot's shift to being a manager. In traditional cockpits where the pilot was required to perform all actions, a well-defined scan was needed to ensure that all the important information was perceived. As more flight experience was gained this scan pattern became highly automated and occurred with little conscious effort. Using such a scan pattern meant that sampling of all flight parameters occurred at regular intervals. If the scan failed the result was usually immediately obvious in the pilot's aircraft handling. However, in modern cockpits such scan patterns are no longer needed. Instead the pilot uses information searches to seek out the information that is needed to confirm system operation and flight status (Sarter,

1995). This introduces the opportunity for the pilot to focus on one set of goals and miss potentially critical cues not deemed important in the current mental model.

Another pit fall of searches driven by mental models is that people tend to perceive information they are expecting more rapidly than information that is in disagreement with their current assessment (Endsley, 1994; Endsley, 1995b; Fracker, 1988; Jones & Endsley, 1996). In some cases, the desire to persist with the mental model assessed to be applicable to the current situation will cause an individual to ignore new information that does not support their assessment. Alternatively, rather than dismissing the information altogether, it may be considered insignificant or rationalised to support their current assessment (Degani et al., 1999). This tendency is very dangerous, and must be recognised by the experienced operator otherwise their SA will suffer, rather than benefit, from their previous experience.

Effect of Automaticity on Situation Awareness

Automaticity describes the ability to perform tasks in response to environmental stimulus in a fast efficient manner without having to think about the action required. The individual does not need to consciously select an option and then implement the required action; perception is followed immediately by action and appears effortless or easy (Endsley, 1995b). Therefore, automaticity provides another function to avoid the limitations of working memory, and increase the speed with which an individual can operate in a situation. However, even though automaticity occurs below conscious attention, it is still relevant to development of SA, which is a process of the conscious mind. To perform automatically the individual must have perceived the Level 1 elements that triggered the automatic process, and more than likely will be aware of the action required and preformed. Therefore, they are likely to have a conscious awareness of events even if they occur through automatic processes (Endsley, 1995b).

Another issue that should be considered when discussing the impact of automatic processes on SA is the fact that they are processes that do not occur in isolation. While not directly relevant to the argument that automaticity contributes to SA, there is cause to believe that the operator will know many of the Level 1 elements that trigger automatic processes. In dynamic environments there will be many tasks competing for the operator's attention simultaneously (Adams et al., 1995). Each of these tasks will

have a specific subset of environmental elements relevant to completion of those tasks (Kass, Herschler, & Companion, 1991). Consequently the operator must identify the cues relevant to each task from the environmental noise. As several tasks, or objectives, will be in operation at one time, there is a high probability that an overlap in the monitoring demands for each task will occur. This will lead to one environmental cue being relevant to more than one task, including automatic processes. For example, an experienced pilot will be able to maintain airspeed on approach with relative ease, and more than likely, not consciously attend to the thrust adjustments required. The action of maintaining airspeed occurs automatically, however, knowledge of airspeed is also important in the overall appreciation of the approach profile and, therefore, is an element needed to develop awareness in another area. For example, an aircraft's rate of descent on a three-degree approach profile is directly related to the aircraft's airspeed and the wind speed, or effectively the aircraft's groundspeed. By monitoring the aircraft's airspeed and rate of descent to maintain the approach profile, the pilot is provided with a clue to the environmental conditions the aircraft is encountering. For instance, if the required rate of descent to maintain the approach profile changes while the airspeed remains the same, this may indicate a change in wind direction or speed. Such an indicator should trigger an awareness of changing weather conditions and, depending on other elements, arouse the pilot to the possibility of windshear. The ability to anticipate impending wind shear conditions is often vital to the safe conduct of the aircraft. Changes in wind condition can often occur at such a rate that the aircraft cannot maintain a safe flying speed during the change in wind condition. If changes of this magnitude occur the only option to prevent the aircraft from prematurely contacting the ground is to initiate a missed approach before penetrating the windshear conditions. Therefore, while automaticity may be used to control airspeed, the pilot will still be aware of the actual value of the airspeed and its rate of change due to an overlap in SA requirements.

By promoting fast efficient processing of environmental stimulus automaticity can benefit an individual's SA by reducing the time spent evaluating one subset of stimulus, permitting a higher scan rate. As stated, some appreciation of all potentially significant elements is needed to maintain a good overall SA and avoid cognitive tunnelling (Endsley, 1995b). A higher scan rate will promote better sampling of environment elements increasing the chance that significant elements will be perceived, which can

ultimately promote better SA. In addition, by allowing certain functions to occur without conscious attention, automaticity frees cognitive resource that would have otherwise been consumed performing those tasks. In turn, this allows those resources to be applied to the more dynamic, or novel, information in the environment.

As a result of these benefits provided by automaticity considerable workload is removed from working memory, allowing the individual more capacity to deal with other tasks such as goal selection and prioritisation. Ultimately, if an individual is able to evaluate the appropriateness of current goal selection, it is more likely that a better plan will be developed and a smoother ride will result.

2.7 Effect of Motivation on Situation Awareness

As discussed the ergic tension level reflects the strength of the drive an individual experiences to achieve an objective. If the ergic tension level is low, the individual would not be compelled to observe relevant elements, nor would they feel an emotive response to those elements if observed. They would also not be compelled to attain the objective of that tension. Conversely, if the ergic tension level is high, the individual's compulsion to attain the goal inherent to the erg would induce them to pay closer attention to certain classes of objects (Cattell et al., 1959). In this way motivation modifies how attention is allocated to the environment, in effect providing a by-proxy indication of arousal. Therefore, as an individual's motivation has the potential to influence their attention allocation, there could be a corresponding influence on their SA. To evaluate this prospect the motivational elements of Assertiveness, Fear (or Escape) and Career have been applied in this study for the following reasons.

Assertiveness Erg

One of the elements of assertiveness is the drive to perform well and to succeed in competition. Therefore, individuals with high levels of assertiveness will obviously want to be seen as good pilots. To achieve this they need to fly the aircraft effectively and smoothly, which requires anticipation of flight manoeuvres and system changes. To be able to achieve either of these goals the pilot needs to have good Level 3 SA that will provide a solid platform from which they can make decisions and take action. Moderate to high levels of assertiveness is, therefore, likely to compel an individual to observe

elements important to the flight task, resulting in better allocation of their attention with the intention of achieving good performance. Consequently, they will probably achieve higher levels of SA, which will be required to ensure the goal of this erg is met.

Fear or Escape Erg

The primary drive of this erg is to avoid danger with regard to accident, illness and loss of life. As a result individuals that possess high levels of Fear erg will also have a heightened awareness of environmental dangers. In the cockpit it seems likely that these people would be motivated to observe those elements that would constitute a threat to the aircraft, consequently requiring a high scan rate. As a result they are likely to have a higher level of SA, particularly for elements that present a significant flight hazard, such as conflicting traffic or height above the ground. However, this will be true only if the individual is not overly aroused by this erg, and suffering from cognitive tunnelling. If this occurs, the individual may concentrate all of their attention on one element that presents a significant hazard to the flight, and become obsessed by it at the cost of observing other situational elements (Fracker, 1989). This will obviously have a serious detrimental impact on the individuals SA. Therefore, a moderate level of this erg may provide the most appropriate level of arousal to promote SA development.

Career Sentiment

This sentiment reflects how well developed the individual's career interest is, which effectively indicates how much time and effort they would be willing to dedicate to their career. It is probable that a moderate level of this sentiment would be necessary to provide the required drive to overcome the many obstacles that will be encountered on the way to reaching an airline aircrew position. High levels of Career sentiment should also compel an individual to learn more about the aircraft and its systems than is required to satisfy licensing requirements. This being the case, they will develop more detailed mental models as a result of the additional knowledge they have gained. Additional detail in a mental model will enhance an individual's ability to make more detailed assessments and provide more accurate default values. As a result the chance the individual will be able to reach high levels of SA should be improved.

2.8 Effect of Level of Automation on Situation Awareness

LOA potentially has a three-fold effect on SA, the first is the need to monitor the LOA being used, the second is whether SA varies as a consequence of the LOA used, and the third is a tendency for the automation to draw the pilot's attention.

New Monitoring Demand

In the first case the various LOA, or modes, that current automation can be operated in imposes new monitoring demands on the operator (Funk et al., 1999; Sarter & Woods, 1992). In addition to keeping track of what is going on in the situation, the operator must also know how the tasks are divided between the operator and the machine. At a low LOA the operator is responsible for all decisions and actions, however, at a higher LOA the machine will assume responsibility for some of the decision-making or action-taking load. If the operator does not know the LOA in use, false assumptions that the machine will perform certain functions may be made. If this occurs, overall performance could suffer as the teamwork between the operator and machine breaks down. Therefore, the operator needs to incorporate knowledge regarding the LOA that is engaged into their SA model to ensure the desired performance will be achieved. Depending on the phase of flight and the rate with which automation mode changes occur, this additional monitoring requirement may result in a cognitive overload situation for the operator. If this occurs fatal flaws in SA could arise as information is missed, or not properly processed under time pressure (Endsley, 1995b).

Relationship Between Level of Automation & Situation Awareness

The second impact LOA may have on SA is whether, in the same situation, SA will vary at different LOA. In other words, what LOA promotes the highest level of SA. It can be reasonably safely assumed that SA will benefit from increasing LOA as the workload placed on the operator is reduced (Endsley, 1995b). However, the relationship between LOA and SA may not be a simple linear progression from low to high. Due to the effects of automation complacency and the time required to interact with the automation, it is possible that there is a LOA that marks a point of diminishing returns, and any further increase in LOA beyond this point will not increase SA (Endsley & Kiris, 1995a; Parasuraman et al., 1993).

Operators who use a system frequently and encounter few problems or automation failures may become susceptible to automation complacency, which is “a psychological state characterised by a low index of suspicion” (Wiener, 1981, p117). Due to the extremely reliable operation of most modern machine agents, operators begin to assume that commands will be carried out as intended, and reduce their monitoring of the actual actions performed. As long as the system performs as expected, task execution will be adequate and the operator will see no negative consequences to their reduced system monitoring. However, in the event that the system does not operate as expected, the likelihood that the operator will detect the anomaly before the error becomes critical is reduced due to their lack of vigilance with regard to system operation (Mosier et al., 1998; Sarter & Woods, 1997). Operating in this manner reflects top-down processing of a mental model, without the associated bottom-up feedback. The operator is merely selecting goals based on a rudimentary situation assessment, and uses the associated mental model to predict resulting environmental states without due regard for how the actual situation may have changed. In this way they will select an operating mode determined to be appropriate by the mental model for that situation. Once this mode is engaged their belief that the system will perform what they expect, as determined by the mental model, leads them to believe there is no need to monitor the system’s actions. However, if their mental model of the system is flawed, or their initial assessment of the situation is incorrect, the system may not perform as their mental model predicts (Parasuraman & Riley, 1997). Obviously, if the actual function of the machine is different from the operator’s expectation, as dictated by the mental model, the lack of monitoring will result in invalidating the operator’s SA (Sarter & Woods, 1997).

The problem of complacency is one example of out-of-the-loop control issues. Other problems associated with putting the operator further away from direct control of the system by introducing more layers of automation are; passive processing of environmental cues, loss of or change in feedback and loss of manual skill (Endsley & Kiris, 1995a). Both passive processing and feedback issues will affect the SA process directly, while loss of manual skill may have an indirect influence on SA through increased automation complacency.

The time required for the operator to interact with the automation can also affect the usefulness of a machine agent. If the machine agent requires the operator to dedicate

most, if not all, their attention to the operation of the system for a sustained period the operators environmental scan will be interrupted. As a consequence of this interruption to their scan, Level 1 of the SA process will be halted causing the operators SA to collapse. In addition to seriously affecting the pilots SA process directly, interrupting the environmental scan reduces the possibility that the operator will detect environmental cues indicative of a situation that could seriously affect completion of the primary task. Under normal circumstances these elements might not be part of the environmental search directed by a mental model, however, they would trigger bottom-up processing of a mental model that ultimately contributes to SA. Removing this vital bottom-up processing feedback will also halt an integral part of the SA process that can detect development of significant environmental situations.

Redirection of Attention

A third potential consequence of increasing the LOA, and putting the operator in the position of monitoring and controlling the automation, is to focus the operator's attention on the automation itself. As the operator's attention is drawn to monitoring the automation, their SA will also be biased toward the machine agent. If more attention is directed toward operating the automation and the information provided by the automation, attention to other elements is likely to suffer (Fracker, 1989). In the case of a pilot operating an FMS, attention will be drawn away from primary flight information, such as altitude and airspeed, and directed toward modes of engagement and FMS operation. Consequently, the pilot will have biased SA toward FMS operation, at the cost of knowing exact primary flight information. Such a tendency might be effective to improve an individual's ability to operate the automation, but will also mean that the operator will not be able to quickly detect inappropriate actions taken by the automation (Palmer, 1995). Therefore redirecting attention, and as a result SA, may promote better operation in most circumstances, but will cause an area of weak SA that leaves the pilot vulnerable to automation dependency. If the automation then fails to perform as expected, the pilot may be slow to detect the failure due to their relatively low awareness of primary data, potentially compromising safe operation of the aircraft.

2.9 Research Questions

1) What level of SA do commercial pilots possess of transport aircraft FMS?

To manage and interact with an autonomous automatic system requires a good understanding of the system, and how it will behave under certain conditions. Failure to properly comprehend a system's settings can result in automation surprises, which can adversely affect the chances of achieving good performance. Therefore, adequate SA of an automatic system is required to manage the associated system effectively.

The data gathered for this study sets out to establish the level of SA that commercial pilots have of aircraft FMS, and how FMS SA relates to their overall SA of the total environment.

2) Does a pilot's level of psychological motivation affect their SA of FMS in any consistent manner?

Motivation to persist with a course of action to achieve a desired goal is an essential element in any career, and is especially true in aviation. Due to the dynamic nature of the aviation environment considerable time and effort is required to learn the skills needed to become a proficient pilot. During every pilot's career it is likely that they will be faced with having to master a skill that they find very difficult on at least one occasion. To master these challenges will require considerable motivation both within, and outside of, the cockpit. The desire to fly must provide sufficient motivation for the individual to learn all they can about the aircraft and its environment, and to apply themselves seriously to the task of flying when in the aircraft. In other words, sufficient motivation is needed to provide the desire to perform well and to apply cognitive resources to the task at hand.

It is hypothesised that at least moderate levels of motivation in the areas selected; Assertiveness, Fear and Career, may be present in pilots who are able to achieve high levels of SA. The reasons for this are two fold, firstly the desire to perform well will most likely motivate the individual to acquire as much knowledge as possible about the aircraft, its systems and the flight environment. This knowledge will aid in the development of more detailed mental models that will assist the

pilot to refine situation assessments. Secondly, while actually flying the aircraft the same desire to perform well, and the motivation experienced to avoid dangerous situations, should cause the pilot to attend to the flight task more studiously. By applying themselves to the situation the likelihood that they will perceive necessary elements is increased, which should heighten the individual's ability to achieve higher levels of SA. By proxy, it is tantamount to suggesting that their arousal will be at an optimum level to develop SA. Overall, it is possible that there is a minimum level of motivation needed to promote development of adequate SA.

3) *How important is a pilot's experience in the flight environment with regard to SA achieved?*

Regardless of the motivation driving an individual to become an exceptional pilot, this goal cannot be achieved without adequate knowledge of the environment and its dynamics. Therefore, in addition to tapping the level of motivation, indicators of pilot experience need to be compared with SA to provide some perspective for the motivational results.

With regard to pilot experience it is hypothesised that; firstly, the more experienced the pilot the better their general aircraft operating schema should be, and therefore, they should be able to achieve good SA in most situations. Secondly, refinement of mental models for automatic aircraft systems, developed through repeated exposures to those systems, should enhance understanding of the underlying operating logic. In turn, greater understanding of system operation should allow an individual to achieve good SA of that system.

CHAPTER 3: METHODOLOGY

3.1 Participants

3.1.1 Operator Experience Required

The focus of this project is to determine whether there is any relationship between pilot SA and motivation, or specific flight experience. To gain data on these elements qualified pilots who have experience operating FMS equipped aircraft were required. As discussed, experience improves an individual's ability to attain and maintain SA in an environment through the development of schemata and mental models. Without these knowledge structures an individual is not able to filter and understand the elements in the environment effectively. Therefore, evaluating subjects with no FMS operating experience would have generated meaningless results unless the subjects had been given extensive instruction on using the FMS. In addition to this, participants would need to spend a prohibitive amount of time practicing FMS operation before any relationship between SA and experience might be revealed. Because of this experience prerequisite, airline pilots represented the most suitable source of candidates for the study.

3.1.2 Recruitment

Recruitment of suitably experienced pilots for this study was undertaken in cooperation with the operations management of Air New Zealand (International), Freedom Air International and Mt Cook Airlines. In total 500 information packs were distributed to the pilots employed by these airlines through internal mail systems. These packs provided information on the intention of the study, the procedures involved and an invitation to participate. Interested pilots were requested to contact the researcher directly for additional information, or if they wished to participate. To increase the profile of the study, a letter of endorsement for the project from the appropriate airline operations management was distributed with the information packs.

In response to the 500 information packs distributed only 6 pilots expressed an interest in taking part in the study. However, due to airline scheduling and personal commitments two of those pilots were not able to participate. Consequently, only 4 pilots were actually able to complete the evaluation procedure, which represents a response rate of 0.8%. To further promote awareness of the study, and the need for

volunteers, the equipment used to perform the evaluations was set up in the crew lunchroom. This also enabled the researcher to speak to pilots before and after flights. In some cases these conversations with a single pilot encouraged other pilots to enquire about the project. In addition to face-to-face contact, a flyer designed to catch the pilot's attention was posted on the wall and notice board in the crew room. This flyer had already been circulated in the information packs distributed to the crews, and the display in the crew room served as another reminder about the project. All of these activities were undertaken with the intention of promoting awareness of the project, to maximise the chance that each pilot would seriously consider participation.

Despite these efforts, the very low number of participants in the study was disappointing, and is an issue that will need to be carefully addressed in future studies. The most significant disincentive to participation was seen as the time required to complete the testing procedure (this is discussed more fully in the Results section). In total 2 hours were needed to complete the evaluation procedures. However, it was not considered feasible to complete the testing in less than 2 hours per candidate without significantly reducing the amount of data, and the quality of information gathered. Despite the small size of the sample, the available data does provide some insight into the nature of SA amongst this group of pilots, and indicates potentially valuable areas of SA research that would be worth pursuing.

3.2 Measures

The focus of this study was to evaluate how pilot motivation and experience might affect SA of aircraft FMS. To achieve this three measurement tools were used: SAGAT, Motivational Analysis Test (MAT), and a biographical experience questionnaire. The sections that follow describe the development and use of these measures as applied in this study.

3.2.1 Application of the SAGAT Technique

The Simulator

To apply the SAGAT technique participants were required to perform an A to B flight during which stops were made to administer SAGAT queries. In this study the GNS-XIs programme, which is a PC based FMS part task simulator, was used as the platform for

the participants to perform the primary flight task. The programme was run on an IBM compatible 486 computer running at 66Mhz, and was entirely operated by using a pointing device, in this case a computer mouse. The simulator could only be flown by reference to cockpit instrumentation, as no out-of-the-window view was available.

The GNX-XIs programme simulates a generic twin-engine turbine powered aeroplane. The flight dynamics simulated were sufficient for the purposes of this study, but did not accurately reflect operation in a real aircraft. For example, there was no effect on flight performance with change in altitude or changes in aircraft configuration. There was also no minimum speed, or stalling speed, and the aircraft continued to fly with virtually no airspeed. Despite this, when flown within the normal operating range the aircraft's performance appeared to be essentially normal.

The autopilot in the simulator provided standard heading control, climb, descent, altitude hold and altitude capture functions. However, in climb and descent modes the only way to control the rate of climb or descent was by adjusting the power setting, which is not a standard procedure. Alternatively, the FMC could be engaged to fly the aircraft from take-off to landing once the intended route and vertical profile had been programmed. This method of operation provided for much more accurate flight path control. It was also possible to fly the simulator manually using the mouse, however, this technique was extremely difficult and the autopilot was used at all times during testing sessions. The simulator contained all standard flight displays, and it was possible to display track information in traditional Course Deviation Indications (CDI) or more contemporary map formats.

While the GNS-XIs programme simulated a generic FMS aircraft, with modes fundamentally similar to those in real aircraft, it was not precisely the same as any particular aeroplane fit. Due to this, all participants were essentially system naïve before undertaking the SA data gathering flights. This had the benefit of ensuring a level playing field for all participants, as none of the potential candidates would have had prior experience operating the simulator interface. The novelty of the simulator would therefore require the participants to adapt to the nuances of the system.

The design of the GNS-XIs simulator also meant that pilots with experience operating glass cockpit aircraft were needed. To transfer to a new system that has operating principles fundamentally similar to those with which an individual is familiar, requires use of generic schemata and adaptation of mental models. Mental models will need to be altered due to the change in feedback type and location, and the subtle differences in mode operation. For example, the type of FMS aircraft flown by participants involved in this study have two modes that can automatically maintain a desired track. One mode can follow navigation signals from ground based radio aids, while the other follows onboard FMC derived track information. In the real aircraft each mode has its own mode select button that can be pressed to engage the associated mode to command the autopilot. However, in the simulator the same mode select button engaged either the FMC or radio aid tracking functions. The navigation information followed by the simulator was then determined by the information displayed on the horizontal situation indicator, which is the main navigation display. While the modes in both the aircraft and simulator perform the same function, the method of engagement is very different requiring adaptation of the mental model for that function. Greater benefit will, therefore, more likely be gained from applying the more generalised schemata that provide an overview of system function than the detailed mental models. Due to the underlying similarity between the simulator and most aircraft FMS designs, schema that provide the high level understanding of system function can be applied to the new environment relatively easily. Therefore, even though all participants will be new to the system, FMS operating experience was still essential to be able to operate the simulator without extensive training.

In addition to providing a level playing field, the need for participants to adapt to the new system and its particular operating modes will increase the processing load placed on working memory. As long-term memory stores in the form of mental models cannot be immediately matched to the current environment, a greater amount of information will need to be processed in working memory (Endsley, 1995b). The increased processing load placed on working memory may have a positive spin off during testing however, as weaknesses in an individual's SA process are more likely to be revealed under high workload conditions (Selcon et al., 1991).

SAGAT Query Development

To develop the SAGAT query database a delineation of monitoring demands for a pilot performing an A to B flight was first undertaken (Table 2). The monitoring demands, and resulting queries, were based on the SAGAT queries in the Tracon Air Traffic Control Version User Guide, developed by Endsley and Kiris (Endsley & Kiris, 1995b), adapted to the piloting role by the researcher. The delineation of monitoring demands and draft SAGAT queries were then circulated to three senior management pilots in Air New Zealand for comment. The feedback received from these pilots was not extensive, but indicated that they saw no significant problems with the queries developed.

In developing the delineation of monitoring demands in table 2 all the factors that a pilot would need to monitor on an actual flight were considered, and not just those applicable to the FMS. This ensured that the queries developed adhered to the global evaluation technique inherent to the SAGAT procedure. The need for this design was essential to avoid directing the participant's attention to any one aspect of the situation of most interest to the research. In addition, developing queries on a global basis enables the testing procedure to capture any bias in subject SA toward a particular area of the environment. As a result it is possible to evaluate if the subjects were cued to direct their attention to one area of the environment more than any other.

Table 2: Monitoring Requirements on an A to B flight.

Objective: Fly A to B safely and efficiently. To achieve the objective the following elements need to be monitored.
Take-Off
Take-off thrust set, and achieved. Monitor engine status (temperatures and pressures) Maintain runway centre line. Monitor acceleration. Awareness of V_1 and V_R Verify FMS TOGA mode changes to throttle hold. Weather and, in particular, wind appreciation
Initial Climb
Achieve positive ROC Monitor speed build up (in relation to minimum manoeuvring speed and flap schedule) Monitor altitude (minimum safe height for departure turn) Set climb thrust. Monitor track (location) Verify FMS heading or lateral navigation mode is engaged as appropriate. Monitor ATC and traffic Monitor significant weather (cross-wind/ turbulence)
Climb
Monitor power and pitch (relates to ROC & speed) Monitor ROC (is it normal) Monitor speed control

<p>Monitor system status (i.e. fuel management & cabin pressurisation) Normal FMS and autopilot actions after autopilot engagement Verify appropriate FMS climb mode engaged (in light of the intended vertical profile) Monitor altitude (in relation to next target) Monitor track (location) Monitor ATC and traffic Monitor significant weather (cross-wind/ turbulence)</p>
Cruise
<p>Monitor altitude Monitor speed Monitor fuel status Monitor track (location) Next waypoint ETA Monitor significant weather (cross-wind/ turbulence) Verify correct FMS modes to maintain desired track and altitude (monitor for mode disengagement) Monitor ATC and traffic</p>
Descent
<p><i>Approaching TOD</i> Knowledge of TOD position Proper system state for descent <ul style="list-style-type: none"> i. FMS descent mode armed and FMC programme complete ii. A/C system (i.e. pressurisation, fuel etc) <i>After TOD</i> Verify engines stable. Monitor speed and pitch (relates to ROD) Monitor ROD (is it normal) Monitor altitude (in relation to next target & profile) Monitor track (location) Manage aircraft energy, considering: <ul style="list-style-type: none"> i. Speed ii. Altitude iii. ROD iv. Rate of change of i, ii & iii Verify correct FMS mode status to follow descent profile (monitor mode captures/reversions) Monitor ATC and traffic</p>
Approach
<p>Manage aircraft energy, considering: <ul style="list-style-type: none"> i. Speed ii. Altitude iii. ROD iv. Rate of change of i, ii & iii. Verify appropriate descent and heading modes engaged and approach mode armed if appropriate. Track aircraft configuration (wing flap position and landing gear status). Monitor distance to touchdown and final approach fix (location). Deviation from approach profile. Position in relation to final approach course (deviation). Traffic sequence and ATC Weather and wind (gustiness)</p>
Landing
<p><i>Before Touchdown</i> Final rate of descent. Deviation from final approach speed. Aircraft configuration (correct flap position and landing gear extended). Threshold crossing height accurate. Centre line tracking accurate. Autopilot and auto-throttle modes correct.</p>

After Touchdown

Keep aircraft straight.
Brakes engage.
Spoilers deploy.
Reversers engage.
Rate of deceleration adequate.

Reviewing the monitoring requirements for each phase of flight in Table 2 revealed that there were elements that needed to be monitored in virtually all circumstances. By extracting the elements that were common to all flight situations it was possible to identify generic categories of monitoring demands that were applicable to the operation of any auto-flight system. The generic monitoring requirements identified were:

- ✦ Monitor manual and automatic FMS mode changes, including autopilot engagement.
- ✦ Monitor heading and track.
- ✦ Monitor performance (pitch, power and airspeed).
- ✦ Knowledge of position in relation to next significant flight target (e.g. next waypoint, next target altitude, etc)
- ✦ Weather appreciation.
- ✦ Knowledge of ATC and air traffic situation.
- ✦ Monitor aircraft system status (e.g. fuel, pressurisation etc)

A pool of 27 queries relevant to operation of an FMS equipped aircraft, and in particular, relevant to the GNS-XIs simulator was developed from the generic monitoring requirements that had been established. These questions are shown in Table 3.

Table 3: SAGAT queries used

Situation Awareness Queries
Level 1 SA Queries. Perception of relevant elements in the environment.
1) Select the engaged horizontal navigation mode(s).
2) Select the engaged vertical navigation mode(s).
3) Select the VOR station(s) tuned on the radio stack.
4) Select the NDB station(s) tuned on the radio stack.
5) The landing gear is; UP, IN TRANSIT, DOWN.
6) Enter the altitude set in the altitude window.
7) Select the next waypoint.
8) Enter the aircraft's ground speed.

<p>9) The aircraft heading is closest to; N, NE, E, SE, S, SW, W, NW</p> <p>10) Enter the aircraft's current altitude.</p> <p>11) What is the aircraft's current rate of climb/descent.</p> <p>12) Select the area in which the aircraft is located.</p>
<p>Level 2 SA Queries: Integration of environmental elements and operator goals to form a mental picture of the situation.</p>
<p>13) Select the roll mode(s) that will cause an immediate change in the achieved flight path if engaged.</p> <p>14) Select the pitch mode(s) that will cause an immediate change in the achieved flight path if engaged.</p> <p>15) Select the primary navigation aid.</p> <p>16) What is the time to the next waypoint?</p> <p>17) The autopilot is actively tracking the desired route. True/False</p> <p>18) The aircraft heading is the same as the heading bug setting. True/False</p> <p>19) The current power setting is appropriate for the phase of flight. True/False</p> <p>20) The vertical profile programmed into the FMC is being followed. True/False</p> <p>21) Select the icon that represents the difference between the aircraft's altitude and the target altitude.</p> <p>22) An end of descent waypoint exists in the current FMC programme? True/False</p>
<p>Level 3 SA Queries: Projection of the metal model to anticipate future events.</p>
<p>23) Will the aircraft automatically turn to follow the desired route after the next waypoint? True/False</p> <p>24) Will a change in wind direction or strength be adjusted for automatically? True/False</p> <p>25) In the current configuration, will moving the heading bug cause the aircraft to turn? True/False</p> <p>26) In the current configuration, will the aircraft automatically capture/track the desired course? True/False</p> <p>27) With the current set up, will the aircraft automatically descend at Top of Descent? True/False</p>

Authorware Query Administration

To administer and record responses to the SAGAT queries a laptop computer with an Intel Pentium 150MMX processor was used. This computer ran a query administration programme created by the researcher using Authorware4 that was specifically designed for this study (Appendix 1). This programme contained all the SAGAT questions developed for the study and administered those questions in random order at randomly selected times chosen by the programme. All operating logic and interface design used in the query administration programme was developed by the researcher, as no off-the-shelf solution was available.

The logic built into the query administration programme was based on the guidelines established by Endsley (1995a). Consequently, no two simulation freezes to administer

SAGAT queries were closer than 3 minutes apart and each stop lasted for a maximum of 2 minutes, after which no more queries were presented and the participant was prompted to return to the simulation. If the participant managed to answer all 27 queries before the 2 minutes expired, they were prompted to return to the simulation once each query had been administered once. The random selection of times for simulator freezes, and presentation of queries in random order ensured that the procedure also adhered to the guidelines developed by Endsley (1995a). By freezing the simulator at randomly selected times it is very unlikely that participants could anticipate simulator freezes. Consequently, the chances of them artificially increasing their scan rate, and as a result their SA, before a freeze was minimised. The random selection of SAGAT queries was used to prevent any trend in the line of questioning becoming evident. By randomly selecting the queries to administer at each stop, each query has an equal chance of being presented. This avoids biasing the number of times any one query is administered and the possibility of cueing the participant's attention to any one area of the situation. Random query presentation also allows the results from different SAGAT trials to be compared (Endsley, 1995a).

The query administration programme also recorded the participant's response to each query and the order in which the queries were presented. The programme compiled this record by generating a text file and adding each query presented, and the selected answers to those queries, to this file.

As stated by Endsley (1995a), SAGAT queries should be designed to present information in a format with which participants are familiar. This ensures that any SA related knowledge, or default values held in mental models, is triggered. In turn, providing a more accurate picture of the knowledge that the individual can bring to bear on the situation to facilitate understanding. As any knowledge leading to understanding of the environment can benefit SA, gaining a measure of this knowledge is important. To apply this concept in the current study, graphical representations of simulator displays were incorporated into SAGAT queries wherever possible. For example, the queries used to question participants about the autopilot modes that were engaged presented an accurate representation of the GNS-XIs autopilot panel, including operational mode select buttons (Figure 4). To answer the query, participants merely had to select the mode they believed was engaged by clicking on the appropriate button,

as they would in the simulator. To provide the participant with feedback on the options that had been selected, selected options would change colour. In the case of the autopilot panel in Figure 4, the mode select buttons would change to bright green when the mouse pointer was moved over the respective button, and once the mode had been selected, the colour of the button would remain bright green.

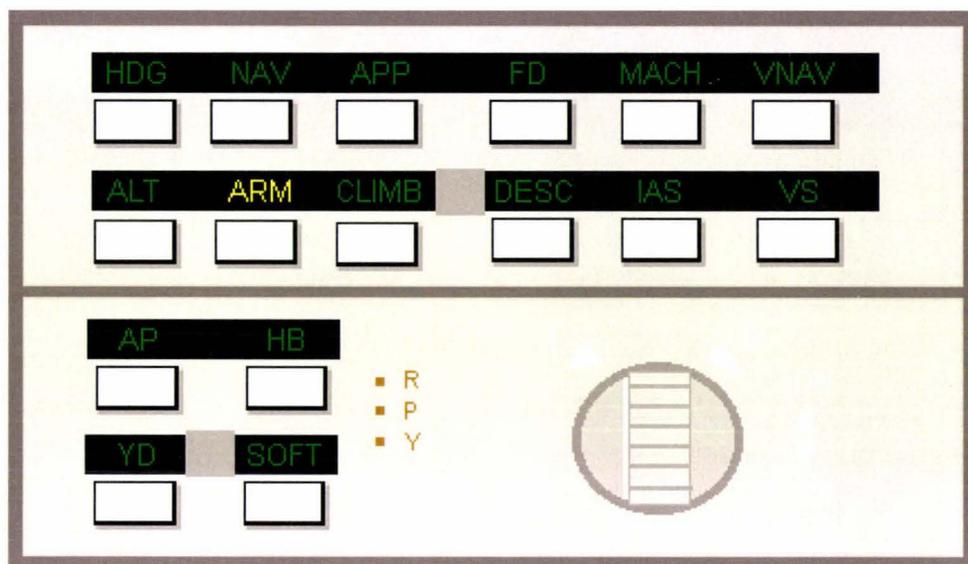


Figure 4: GNS-XI's Autopilot panel graphic used in SAGAT queries

The design of the query programme interface allowed the subject to select more than one option for each query, which was necessary as in certain circumstances the correct response to some queries required more than one selection. Once the subject was satisfied with their selected option, or options, clicking on a button labelled Next Query continued the query administration. As would be expected, selecting the Next Query button caused the programme to display another query. The query displayed by the programme was randomly selected from those queries that had not already been presented during that simulation freeze. Upon selecting the Next Query button the programme also added the selected options for the current query to the text file, thereby generating the list of queries and answers required for assessment.

This style of interface design also allowed the participant to change their answer several times before deciding to continue. There was no penalty for changing the selected answer, as the query administration programme only recorded the selected options when the Next Query button was pressed. If a query was presented that the participant did not

know the answer to, or could not estimate what the answer might be, a Skip Query button was provided. When the Skip Query button was selected, the programme would randomly select another query that had not already been administered for presentation to the subject. At the same time, the query that was skipped was recorded in the text file, with a comment that the query was skipped regardless of the options that may have been selected. Any skipped queries were then marked as incorrect when assessed, as recommended by Endsley (1995a).

Once each query had been answered, or after two minutes had elapsed, the query administration programme would clear the screen and present a message instructing the participant to return to the simulation. This occurred even if the participant had not answered the query currently being displayed at the end of the two-minute interval. However, the programme did not record queries that were automatically cleared before the participant had selected an answer. Upon completion of the 2-minute query session the programme generated a random time that was required to be greater than 3.5 minutes, and less than the maximum time established for the current flight. A time within these limitations was required to ensure that the desired number of stops could be made, even if all stops occurred at the maximum time between freezes for each SAGAT query administration. The query administration programme then waited for the randomly generated time to elapse before generating a chime sound to indicate that a SAGAT query session was to begin. This process continued until the desired number of stops for that flight had been achieved. After the last SAGAT query administration had been completed the participant was prompted to return to the simulation in the same way that had been used after all SAGAT freezes. However, in this case the programme had actually finished, and no further freezes to administer queries would occur. This was done to avoid arousing the participant's attention to the fact that the testing element of the flight was over, and minimise any tendency for the participant to then consider the flight complete before landing the simulator. While not affecting the SA results for that flight, this procedure was used to minimise any flow on effect that might influence SA scores of following flights by maintain consistency between flight exercises.

Data Collection Technique

To gather data on participant's SA both the GNS-Xls and laptop computers were used in concert. The procedure involved the participant beginning the flight using the GNS-

XIs simulator, and at the same time the researcher starting the query administration programme. The participant was instructed to attend to all the tasks they would normally perform in the real aircraft, while pseudo Air Traffic Control (ATC) was provided by the researcher. After a random period of time determined by the query administration computer, the computer would generate a chime sound indicating to the participant that they were to begin answering the SAGAT queries. Once the chime was heard the researcher paused the simulation and the screen was covered with a cloth to prevent the participant from viewing any of the simulator displays. The participant then began to answer the queries presented on the laptop computer.

As described, the query administration programme recorded the participant's response to each query and the order in which the queries were presented. To provide a record of the situation in the simulation for comparison with the participant's responses, the researcher took photographs of the simulator screen at random intervals (see Figures 5 to 8). This was necessary as the GNS-XIs simulator was not capable of recording a log of events that occurred during the flight. Photographs were taken at random times to avoid cueing the participants to the possibility of a query stop. In addition, as the researcher did not know the random time generated by the query programme, the likelihood of there being any correlation between screen photographs being taken and query stops was minimal. To supplement the screen photographs the researcher also recorded the selected autopilot modes, and the stop time so that the appropriate photographs for each set of queries administered during a stop could be identified and rated.

The Flight Schedule

Each participant undertook 3 flights that required 30 minutes each to complete, including the stop times to administer SAGAT queries. All stop times were arranged to comply with the minimum time between stops, and maximum time for a freeze established by Endsley (1995a). The first of these flights was a practice flight to familiarise participants with the simulator interface and mode logic. During the practice flight 4 stops to administer SAGAT queries were made to allow the participants to become familiar with the query system. These stop times were randomly generated and were at least 3.5 minutes apart.

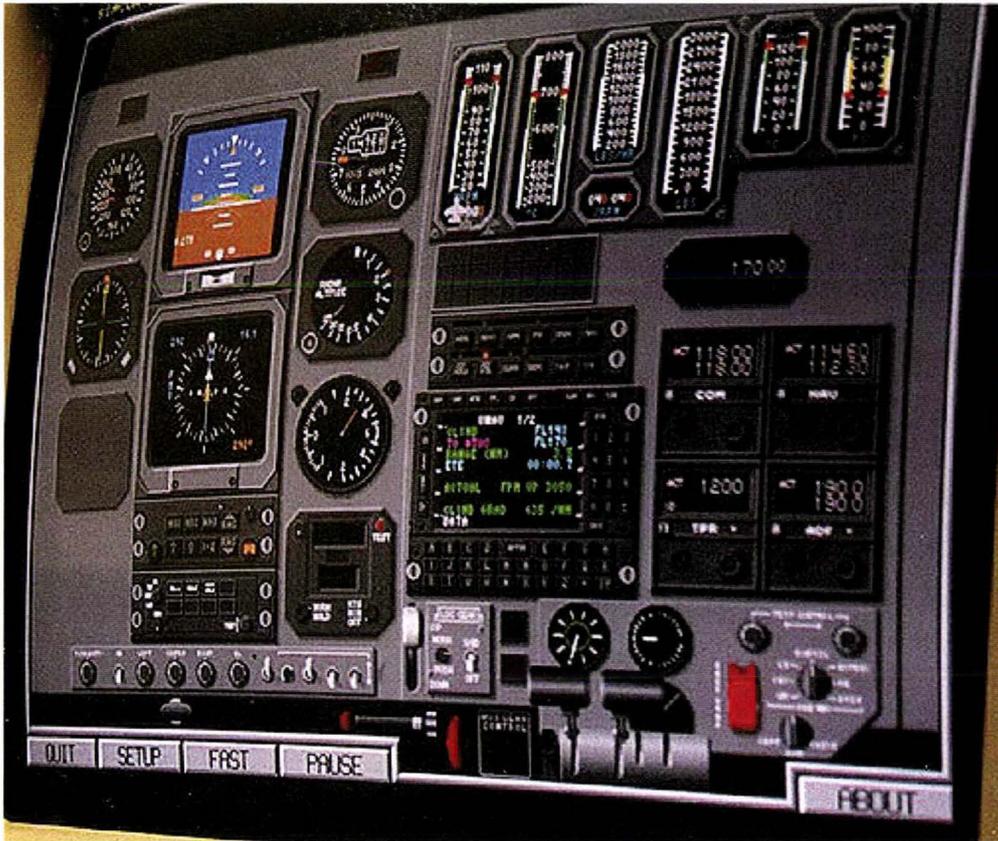


Figure 5: GNS/XI simulator screen shot while in climb.



Figure 6: GNS/XI simulator screen shot with autopilot altitude window open.



Figure 7: GNS/XI simulator screen shot while turning overhead a waypoint.



Figure 8: GNS/XI simulator screen shot with FMC panel open.

Due to the need to change computers to answer the queries these stops were particularly useful to clarify any procedural misunderstandings. No screen photographs were taken during the practice session, and the responses to SAGAT queries were not rated.

Flights 2 and 3 were data gathering sessions and screen photographs were taken during these sessions for rating purposes. The flight time of the second flight was 22 minutes excluding query stops, during which time 4 query administration stops were made. The interval between stops times was at least 3.5 minutes, and a maximum 5 minutes so that all 4 stops could be made within the flight time. This flight involved a simple route change to force the participants to interact with the FMS. The third and final flight had a flight time of 16 minutes excluding simulation freezes and incorporated 3 query stops. Again the stop times were randomly chosen and did not occur closer than 3.5 minutes, or more than 5.25 minutes apart. To challenge the participants further, this flight required a return to the departure airport, which needed considerable replanning and reprogramming of the FMC. The changes to the intended flight plans were incorporated to increase workload and to force the participants to interact with the aircraft systems.

To evaluate the viability of using both computers in the testing procedures, and the interface design of the SAGAT queries, a trial session was run. During this trial a flight naive volunteer completed all three flights, and the responses to SAGAT queries were recorded. However, the accuracy of responses to the queries presented was not rated. As a result of these trial flights the dual computer test technique and the flight schedule was found to provided the desired result. Completion of the SAGAT queries also presented no significant problem, and the interface appeared to provide the intuitive design desired. This was despite the fact that the volunteer performing the test was not a qualified pilot.

A pilot study using qualified aircrew to evaluate the SAGAT test procedure, as applied in this study, was not undertaken due to the considerable cost and danger of depleting the small pool of potential participants for the main study. In combination with the limited time frame available to complete the data gathering phase of the project, a viable pilot study using the procedure with qualified aircrew was not possible.

3.2.2 Motivation Analysis Test

To measure participant motivation the Motivation Analysis Test (MAT) was administered. The MAT was designed to capture the ten dynamic motivational structures, shown in Table 4, known to be present in the average normal individual (Cattell et al., 1959).

The MAT is an objective measurement device that uses four testing techniques to measure the level of each erg and sentiment, rather than using self-rating techniques. The four tests employed are End-for-Means (projection), Autism, Ready Association and Means-End Knowledge (Cattell et al., 1959). Scores from each sub-test can be combined to provide a motivational rating for each erg or sentiment, or to generate an overall motivation rating.

Table 4: Dynamic factors measured in MAT

Ergs	Sentiments
Mating (Sexual love)	Sentiment to self
Assertiveness (Achievement)	Superego
Fear (Escape)	Career
Narcism (Comfort, sensuality)	Sweetheart-spouse
Pugnacity-sadism (“aggressiveness” of a specific kind)	Home-parental

Source: Cattell, R. B., Horn, J. L., Sweney, A. B., & Radcliffe, J. A. (1952). *Handbook for the Motivational Analysis Test “MAT”*. (Second ed.). Champaign, Illinois, USA: Institute for Personality and Ability Testing, p2.

To complete the entire MAT questionnaire requires approximately 1 hour, however, due to the need to keep the testing time down and the fact that only a few test factors were of interest, a shortened version of the questionnaire was administered for this study (Appendix 2). The factors of interest taken from the MAT questionnaire were Assertiveness, Fear and Career. The questions from each sub-test relating to these factors were extracted from the MAT and used to obtain motivation scores for each participant. While compiling the shortened MAT questionnaire, the opportunity was also taken to make minor revisions to some of the language and subject matter of the

original MAT questions. This was needed to increase the relevance to current societal values and New Zealand culture. An example of the changes made is as follows.

Original MAT question.

More research money should be spent on:

- Dressing the nation in smarter styles and new fabrics.
- Finding cures for radiation sickness.

Revised question used.

More money should be spent on:

- Developing more attractive public buildings.
- Finding ways to reduce/reverse global warming.

Participants completed the shortened MAT questionnaire prior to commencing the simulated flights.

3.2.3 Experience

To gather information regarding flight experience, each participant completed a simple questionnaire. The form included information regarding total flight hours, flight hours on FMS equipped aircraft, aircraft type ratings gained, any instructor ratings gained and the style of their initial flight training (Appendix 3). Even though the information requested only provided a coarse indication of the participant's flight experience, the items were chosen with the intention of identifying whether any particular type of experience might affect SA.

The measures of flight hours were chosen as they provide an indication of the exposure an individual has received to the flight environment. As SA related schemata and mental models develop over time, greater exposure to flying should result in the individual developing more detailed knowledge structures. In turn, the individual should be able to attain higher levels of SA due to the refinement of their schemata and mental models. Questions relating to the style of initial flight training, and whether any instructor ratings had been gained also relates to development of schema and mental models. If the individual underwent a comprehensive initial training course and also learnt the additional skills required to teach others how to fly, the likelihood that their knowledge base would be more comprehensive is increased. In addition, it is likely that

the information they had acquired would be structured in a more accessible useful manner.

Instructor Rating System

To enable analysis of the information gathered regarding instructor ratings held by the participants, the instructor ratings were ranked from 1 to 6. This ranking system was established to reflect the level of proficiency required to qualify for the instructor rating. Thereby establishing a hierarchy of instructor ratings with 6 being the highest, and 1 the lowest rating. This meant that ranking 1 was assigned to the C Category instructor rating, as this is the first instructor rating that can be gained. From here the rankings were assigned as follows; B Category = 2, A Category = 3, Simulator instructor = 4, Training Captain = 5 and Flight Instructor = 6. The higher rankings were assigned to the airline instructor positions (i.e.; Simulator Instructor, Training Captain and Flight Instructor), as experience in these positions was considered more likely to benefit the development of mental models relevant to the operation of FMS aircraft.

3.3 Level of Automation

Current commercial aircraft provide a wide range of LOA that can be utilised by the pilot; in most aircraft the lowest LOA available is manual control, and the highest is supervisory control. In contrast to this wide range provided by the real aircraft, the GNX-XIs simulator was capable of being operated in only two LOA, batch processing provided by the autopilot, and supervisory control provided by the FMC. The LOA used in each session was at the discretion of the participant, however, all participants were asked to fly the simulator using the greatest LOA available. This request was made to encourage use of the FMC, which can impose high workload and increased SA demands when a situation is changing rapidly. Due to the relatively long time required to update an FMC route programme, effective FMC utilisation requires good anticipation and planning. If the FMC is not correctly programmed for the next route segment before reaching the beginning of that segment, mode reversions may occur due to the lack of direction being provided by the FMC. When mode reversions occur the actions required to maintain a suitable flight path while updating the FMC programme will then be required simultaneously. These events will increase workload considerably and still require very high levels of SA. Therefore, by asking participants to use the

highest LOA available it was hoped that weaknesses in participant SA would become more apparent. However, apart from the direction given to participants to use the highest LOA when ever possible, no quantitative attempt was made to measure the LOA utilised by participants.

CHAPTER 4: RESULTS

4.1 The Sample

As previously stated, of the 500 information packs distributed to active cockpit crews, only 4 pilots participated in this study. This group of pilots consisted entirely of senior flight crew, possessing an average flight experience of 16,000 flight hours, with a standard deviation of 2,708 hours. All 4 pilots were male, and the average age of the group was 52.5 years with a standard deviation of 4.1 years (Table 5).

Table 5: Descriptive Stats of the pilot sample obtained

	N	Minimum	Maximum	Mean	SD
Age	4	47	57	52.5	4.1
Total Flight Hours	4	14,000	20,000	16,000	2,708
FMS Flight Hours	4	3,000	8,000	5,000	2,160

The very low response rate observed in this study is of considerable concern and may indicate an obstacle to future field evaluations of pilot SA. On the whole, while most of the pilots that were spoken to about participating in this study recognised that SA of FMS is a valuable area of investigation, few were motivated to take part. Face to face discussion with pilots who were approached to take part in this study, and with those who did participate, revealed a combination of factors that may have influenced this decision including; scheduled rotation, available free time and perceived individual value gained from participation. In many cases the length of the pilot's flight schedules did not permit them to take part in the study despite the evaluation period running for three weeks. This situation was aggravated by the fatigue that returning pilots experienced, which understandably, did not result in a desire to take part immediately upon their return from a flight. As a result, they opted not to participate in the study. The problem of schedule rotation leads to another potential perceived obstruction to participation, which is the availability of free time. Many schedules only gave the pilot 3 or 4 days between trips. In this time they would have to deal with all the issues that may have arisen while away on schedule for up to a week, in addition to dedicating time to their family. Consequently, the prospect of spending half a day participating in this study was not considered a high priority. The pilots who declined to participate in this study expressed this sentiment to the researcher on several occasions. Obviously the

length of the evaluation procedure has an effect on the significance of this problem. A third possible cause for the low response rate is a lack of perceived value gained from participation. No tangible reward was offered to pilots as an incentive to participate in the study. It is possible that a higher response rate may have been evident if some form of incentive had been offered.

It should also be noted that a lack of interest displayed by pilots to be involved in activities outside of the cockpit was not isolated to this study. At the same time that evaluations were being undertaken for this study, a group of Air New Zealand crews were undergoing an aircraft type conversion that required them to complete a PC based training programme. It is understood that initial response to complete this programme was slow until the deadline for completion approached.

In light of the limited number of cases evaluated, the reporting of results will be presented in a descriptive manner.

4.2 Situation Awareness Results

Of the 27 SAGAT queries listed in table 3, one query was removed after testing as it was considered irrelevant by most participants. This query related to the tuning of a radio navigation aid that had no associated display in the simulator. This gave rise to a situation where the appropriate radio frequency could be set, but there was no display option in the simulator to present the associated navigation information. For this reason most participants did not tune the frequency as the procedure was considered irrelevant to navigation, therefore the question was removed from the analysis. Each of the remaining 26 queries was administered 8.62 times on average with a SD of 2.04.

To generate an SA Score for each participant, the number of questions answered correctly during all testing sessions was divided by the total number questions administered. In effect generating a ratio of correct answers to total number of query administrations, where a score of 1 represents a perfect score. The spread of SA scores obtained ranged from 0.81 to 0.87, with the mean SA score for all participants being 0.845 with a standard deviation of 0.025 (Table 6). The small spread of results is indicative of the small sample size, and the fact that those pilots who volunteered all

reported very similar flight experience. This again highlights the limitations of the sample size, and that it is not possible to make generalisations from this sample to the population. To further evaluate the structure of the SA scores obtained, the questions administered were divided onto groups according to SA level and query focus.

Table 6: Descriptive statistics of participants Situation Awareness scores.

	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Mean	SD
SA Scores	0.81	0.85	0.85	0.87	0.845	0.025

Two comparisons were therefore undertaken. The first, after each query administered was assigned to a category depending on whether the response pertained to Level 1, 2 or 3 of the SA process, and the second was performed after grouping the queries administered in terms of focus on knowledge of FMS or raw/primary data. Primary data refers to information that the pilot would use to manoeuvre and navigate the aircraft without the assistance of automated systems. Such information includes, but is not limited to, the aircraft altitude, airspeed, heading and radio navigation aid track information.

Accuracy At Each Level Of Situation Awareness

Figure 9 shows the cumulative totals after all queries administered had been assigned to categories defined by Levels 1, 2 and 3 of the SA process.

This graph demonstrates that the percent of correctly answered questions was similar for each stage of the SA process. Questions relating to perception of environmental cues (Level 1) were answered correctly 80% of the time, 87% of queries drawing on the persons integrated understanding of these elements (Level 2) were answered correctly, and responses to questions relating to anticipation of future events (Level 3) were 94% correct. This comparison indicates that there was a tendency for these participants to give a greater number of correct responses to queries pertaining to higher levels of SA.

It will be noted that the total number of query administrations for questions at each level of the SA process is quite different. However, when the actual number of queries in the SAGAT database relating to each level of the SA process is considered, the number of

administrations reflects a similar proportion to the actual number of queries (Table 7). Therefore it would appear that the random query administration worked effectively to ensure a relatively even distribution of query administrations.

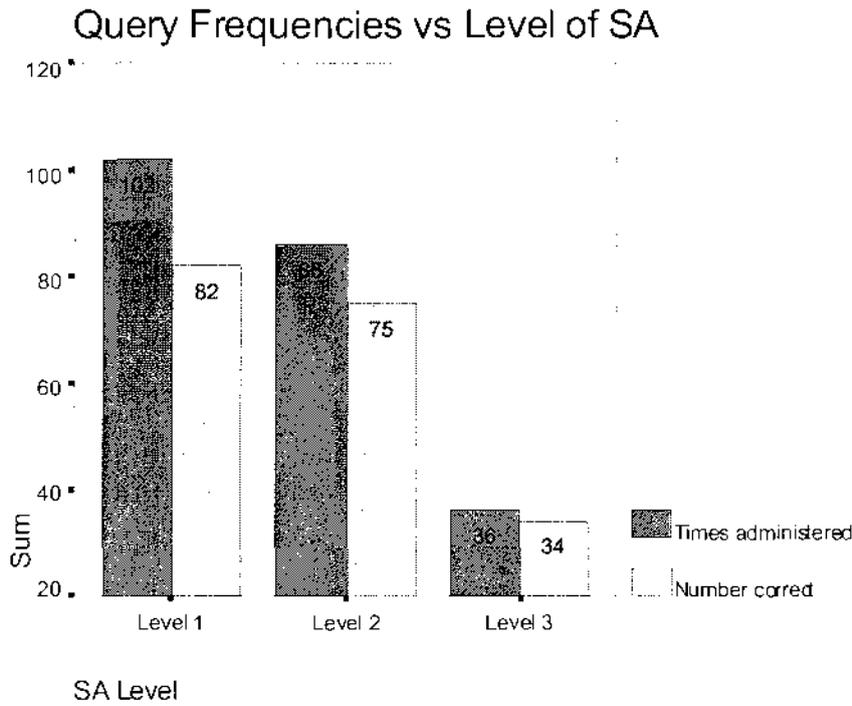


Figure 9: Cumulative totals of SA queries according to Level of SA.

Table 7: Distribution of SAGAT queries at each level of the SA process

	Number of Queries	Percent of Total
Level 1	11	40.3
Level 2	10	38.5
Level 3	5	19.2

Focus Of Situation Awareness

The second consideration, regarding the breakdown of SA results, to be evaluated was whether more questions relating to FMS knowledge or primary data knowledge were answered correctly. Again figure 6 shows the cumulative totals after categorising all SAGAT queries according to FMS or Primary data focus.

The graph in Figure 10 shows a noticeable difference. It can be seen that a much greater proportion of queries relating to the FMS (93%) were answered correctly in comparison

with primary data queries (74%). This represents a difference of 19% in the correct response rate, indicating that there was a distinct tendency for participants to have a more accurate knowledge of the information relating to the FMS.

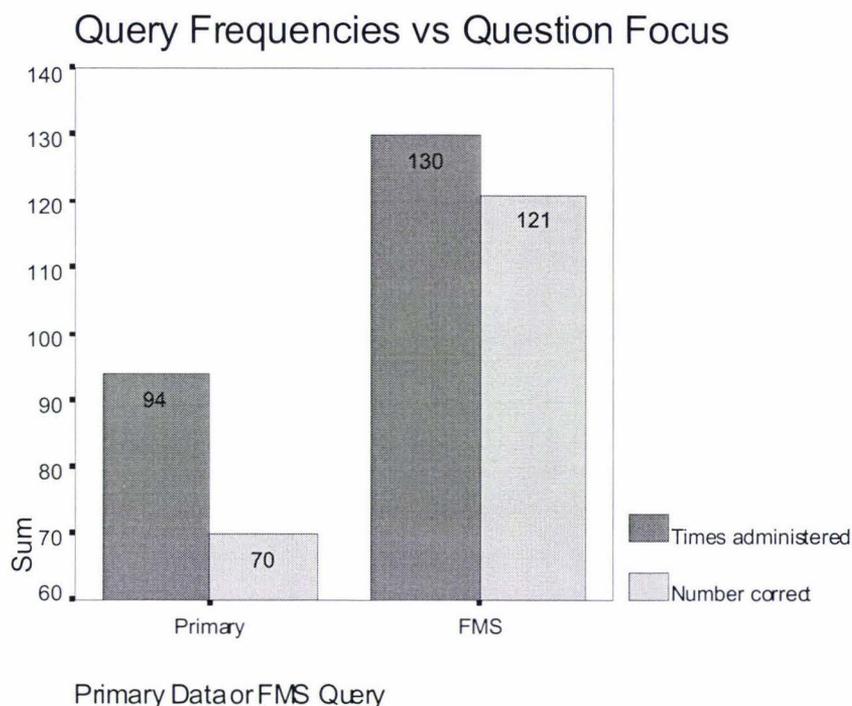


Figure 10: Cumulative query frequency according to FMS or Primary data categorisation.

A similar pattern emerges when the correct response rate to FMS and primary data queries is considered for each participant. Table 8 shows the percent of correct answers given by each participant, and shows that all participants correctly answered a greater proportion of queries pertaining to the FMS than to primary data queries.

Table 8: Percent of correct responses to SAGAT queries

	Primary data Percent correct	FMS knowledge Percent correct	Difference in correct response rate
Respondent 1	75.0% (8)	92.5% (3)	17.5% (5)
Respondent 2	81.0% (4)	96.7% (1)	15.7% (3)
Respondent 3	69.6% (7)	88.9% (4)	19.3% (3)
Respondent 4	72.2% (5)	95.7% (1)	23.5% (4)

Note: the figures in brackets (x) represent the absolute number of incorrect responses.

Similar to the graph for query frequency vs. level of SA, it will be noted that there is quite a difference in the total number of administrations for each type of query relating to FMS and primary data. However, the difference in total number of query administrations for each category was in proportion to the number of questions relating to each category in the query database (Table 9). Again the random query administration technique appears to have achieved an even distribution of administrations for each type of query.

Table 9: Distribution of SAGAT queries relating to FMS or Primary information

	Number of Queries	Percent of Total
FMS Information Queries	16	61.5
Primary Data Queries	10	38.5

The difference between the correct response rates portrayed by this graph was also reflected in comments made by participants. During testing when presented with a primary data question, such as current altitude, each participant on at least one occasion remarked that they had “no idea” what the value actually was. In most cases they then estimated the value of the parameter in question based on a relationship between the parameter and another known element. The lower number of correct responses to primary data questions therefore reflects the reduced accuracy of this estimation technique over recall of the value. However, it should also be noted that while the accuracy of the answers was reduced, the answers were often outside of the acceptable range by a relatively small margin. In the case of responses to queries relating to aircraft altitude, a 500-foot range either side of the actual value was considered acceptable for the intermediate approach phase of flight. A 500-foot range was used as it is a standard tolerance applied during pilot licencing and proficiency checks. In many cases the answers provided by participants were 1000 to 1200 feet off the actual value. Therefore, even though incorrect, the answer provided was not vastly off target.

4.3 Situation Awareness vs. Motivation Results

One of the foci of this study was to identify whether an individual's level of motivation relates to development of better SA. Using the MAT questionnaire the ergs assertiveness and fear (or escape), and the sentiment career were measured. The results from these evaluations showed a large spread of motivational scores (Table 10).

Table 10: Descriptive Stats of Motivation results

	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Mean	SD
Assertiveness Erg	1	7	1	1	2.50	3.00
Fear Erg	8	9	6	8	7.75	1.26
Career Sentiment	7	4	10	9	7.50	2.65

As can be seen, even within this small sample the range of motivation is large, varying as much as 6 to 7 points. Furthermore, the sample size was too small to evaluate whether the SA scores varied with any consistent pattern in relation to this range of motivation results. This limitation is visually illustrated by a series of scatter plots presented for each of the motivational factors.

Assertiveness Erg

With regard to the assertiveness erg, Table 11 shows that three of the four candidates displayed an assertiveness motivation score of 1, however, their corresponding SA scores varied from 0.81 to 0.87. In contrast, Respondent 2 seemed to be an outlier with a considerably different assertiveness factor of 7. The relatively similar level of assertiveness displayed by the remaining group of pilots does not suggest that assertiveness influences SA (see Figure 11).

Table 11: Actual motivational assertive score for each candidate

	Situation Awareness	Assertiveness
Respondent 1	0.81	1
Respondent 2	0.85	7
Respondent 3	0.85	1
Respondent 4	0.87	1

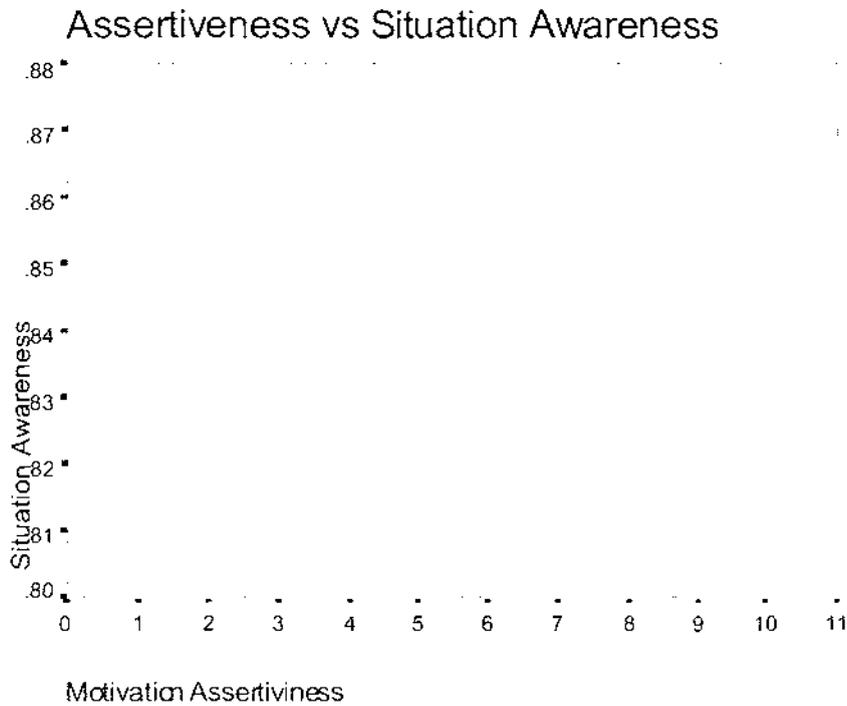


Figure 11: Scatter plot of SA scores vs. Assertiveness Erg

Fear (or Escape) Erg

In the case of fear (or escape) erg, motivational scores were spread over a narrow band of 3 points, while the SA scores ranged from 0.81 to 0.87 (Table 12). As can be seen in Figure 12 none of the participants stood out as having a particularly different level of fear motivation.

Table 12: Actual motivational fear score for each candidate

	Situation Awareness	Fear
Respondent 1	0.81	8
Respondent 2	0.85	9
Respondent 3	0.85	6
Respondent 4	0.87	8



Figure 12: Scatter plot of SA scores vs. Fear Erg

Career Sentiment

Career sentiment displays a spread of motivational scores almost as large as assertiveness, in this case ranging from 4 through to 10. Two respondents, Respondent 2 and Respondent 3, account for the majority of the variation in the motivational results, however, they both achieved the same SA score. In contrast, Respondent 1 and Respondent 4 marked the lowest and highest extremes of the SA scores, but are within only two points of each other in terms of career motivation (Table 13). Such variations do not suggest a relationship of any noticeable effect between career sentiment and SA (Figure 13). It should be noted that in the case of career sentiment, as with the assertiveness erg, Respondent 2 again seemed to be an outlier displaying a career motivation very much in contrast with the other three candidates.

Table 13: Actual motivational career score for each candidate

	Situation Awareness	Career
Respondent 1	0.81	7
Respondent 2	0.85	4
Respondent 3	0.85	10
Respondent 4	0.87	9

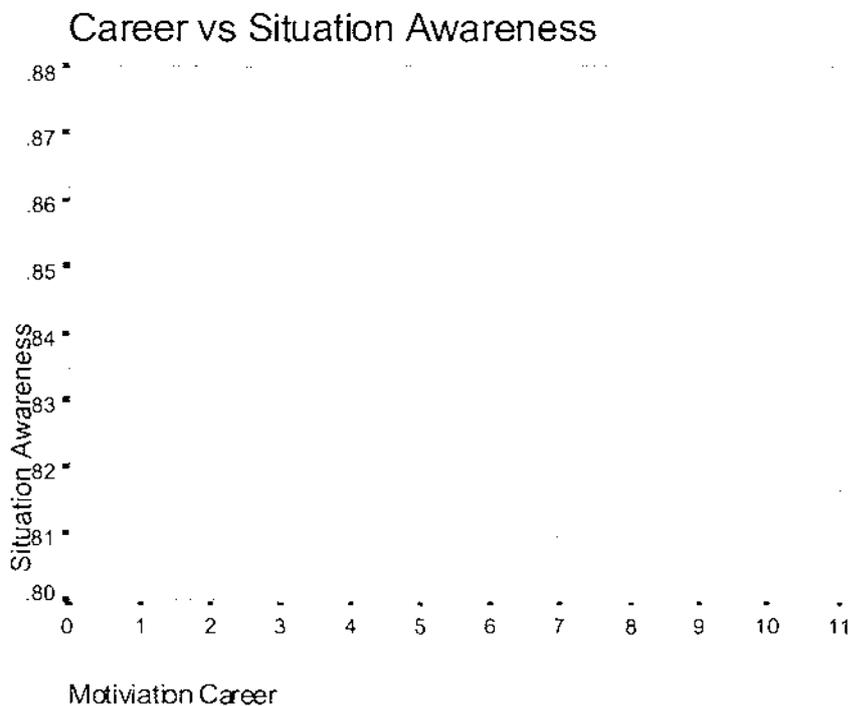


Figure 13: Scatter plot of SA scores vs. Career Sentiment

4.4 Situation Awareness vs. Experience Results

Flight Hours

Table 14 displays the flight hours accumulated by each participant and their corresponding SA score. From this data it can be seen that each participant had gained a substantial number of total flight hours, and each had a similar proportion of flight hours in FMS equipped aircraft in relation to their total flight experience. The pattern for both total flight hours and FMS equipped aircraft flight hours against SA is very similar, merely located at different points along the flight hour scale. What is most striking is that the most experienced candidate, Respondent 2, did not achieve the highest SA score. Despite the high level of flight experience reported by this candidate his SA score was not noticeably higher than the other three respondents. Further more, the difference in flight experience between Respondent 1, who recorded the lowest SA score, and Respondent 3 and Respondent 4 was very little. However, the difference in their SA scores is noticeable. This is visually demonstrated by Figure 14.

Table 14: Actual flight hour experience reported by participants

	Situation Awareness	Total flight hours	FMS flight hours
Respondent 1	0.81	14,000	3,000
Respondent 2	0.85	20,000	8,000
Respondent 3	0.85	15,000	5,000
Respondent 4	0.87	15,000	4,000

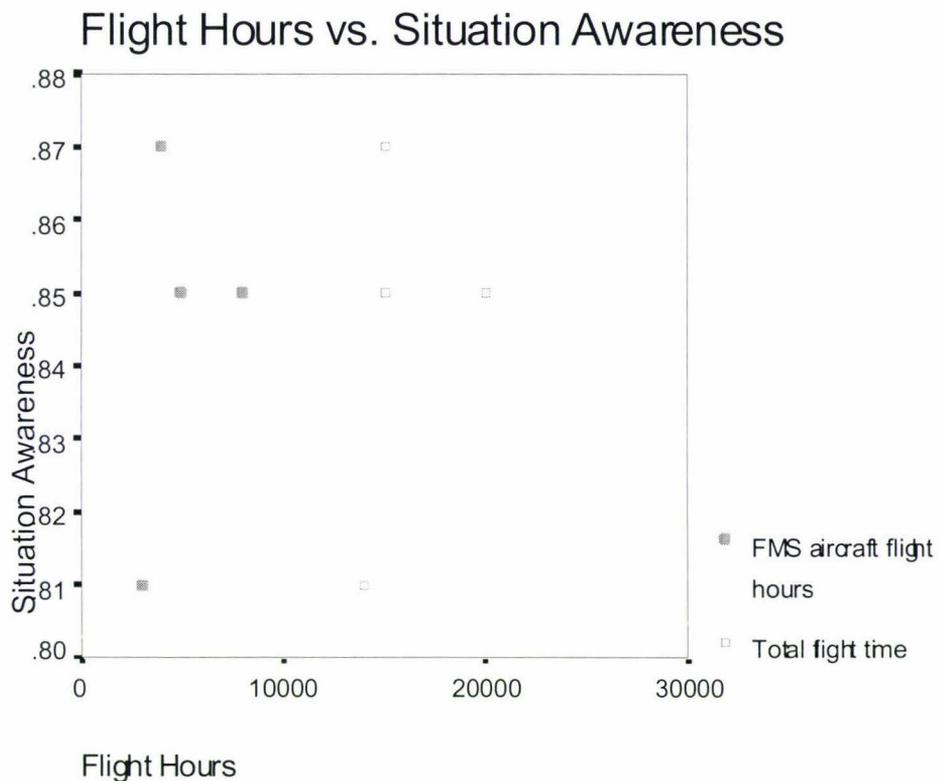


Figure 14: Scatter plot of SA scores vs. Flight hours.

Even though a noticeable relationship between flight hours and SA has not emerged for this group of pilots, it was evident during testing that participants were applying prior experience. Two of the participants made comments at different times during testing that showed they were trying to apply mental models for systems in other aircraft to the simulator. Such comments were, “if this works as it does in the aircraft then I would expect...”, or when answering SAGAT queries, “in the aircraft I would expect this to occur”. Both of these statements reflect the individual’s attempts to resolve ambiguity regarding the actions of the simulator by applying knowledge from mental models developed for other actual aircraft systems.

Type Ratings Gained

To supplement flight hours accumulated as a measure of experience, the number of aircraft type ratings held by each pilot was also evaluated. Type ratings were used as a measure of experience to evaluate whether the development of SA related knowledge structures is influenced by qualitative, as opposed to quantitative, exposure the aviation environment.

As can be seen (Table 15) the number of type ratings does not appear to have a strong influence on SA. Two of the participants had gained ratings in 6 different aircraft types, and also achieved two of the highest SA scores. However, the SA score achieved by Respondent 2 was only equivalent to that of Respondent 3, despite the fact that Respondent 3 only reported a total of 3 aircraft type ratings. Further more, the lowest SA score recorded was for Respondent 1, who also reported a total of 3 aircraft type ratings.

Table 15: Number of type ratings held by participants by aircraft type.

	SA	Traditional A/C Ratings	FMS A/C Ratings
Respondent 1	0.81	2 Jet- (B747-200, B737-200)	1 (B767)
Respondent 2	0.85	4 Jet- (B737-200) Prop - (F27, Viscount, DC3)	2 (B767, B747-400)
Respondent 3	0.85	2 Jet - (B737-200) Prop - (E27)	1 (B767)
Respondent 4	0.87	4 Jet - (B747-200, B737-200, DC10, DC8)	2 (B767, B747-400)

Before going any further it should be noted that only the commercial air transport aircraft type ratings held by each participant have been gathered. Therefore, the total number of ratings for all aircraft types flown by each participant could be quite different. Despite this, evaluating the types of aircraft that participants have flown reveals a different aspect of the experience gained by these pilots. Firstly, Respondent 1 and Respondent 4 both reported that they had gaining ratings for swept wing pure jet aircraft only, however, their SA scores represented the highest and lowest scores measured. In contrast, Respondent 2 and Respondent 3, who achieved the same SA

score, had flown a mixture of swept wing jet aircraft and straight wing propeller driven aircraft. While there is no new pattern displayed by considering the data in this way, Respondent 4 does stand out as having accumulated quite different experience to the remaining three candidates. In this case all 6 aircraft type ratings gained by Respondent 4 were for swept wing jet aircraft, where as the remaining respondents only reported 2 or 3 ratings for such aircraft.

Instructor Rating

As discussed the instructor ratings were ranked from 1 to 6, reflecting the level of proficiency required to gain the respective rating. The top three ranks were assigned to airline instructor positions, as these positions were considered more relevant to development of SA related skills for FMS equipped aircraft. Plotting instructor rating against SA score generated the pattern displayed in Figure 15. The pattern displayed implies a positive relationship between instructor rating and SA.

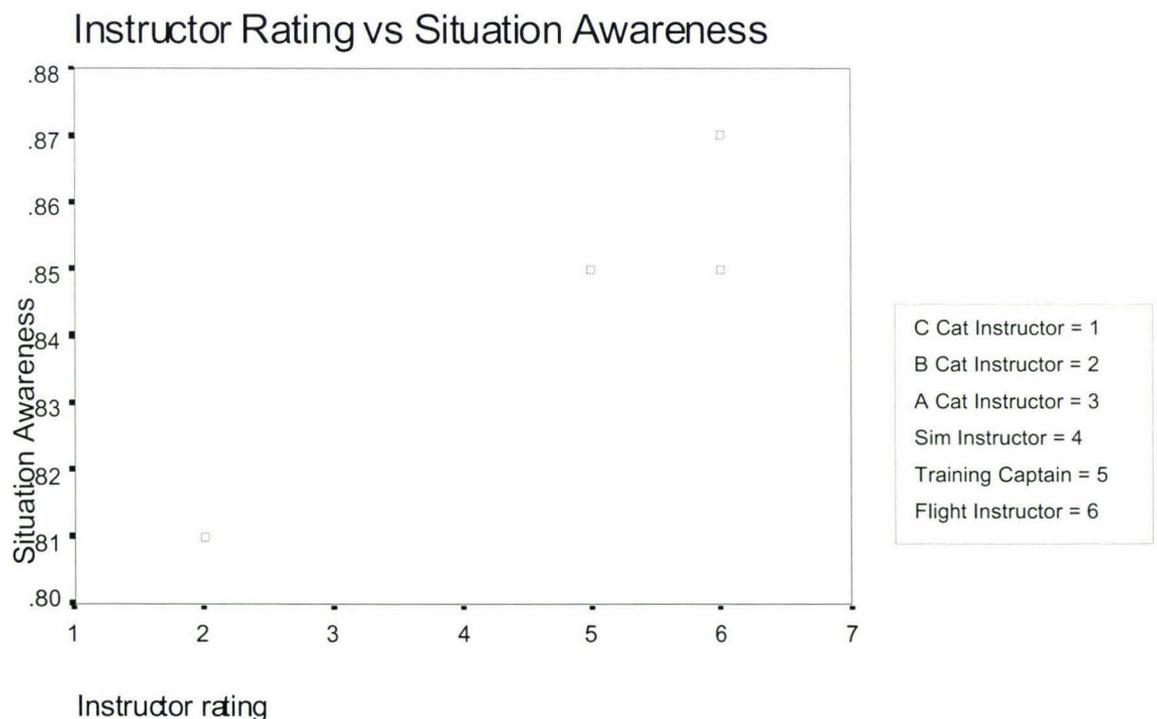


Figure 15: Scatter plot of SA scores vs. Instructor rating.

The outlying case in this instance is Respondent 1 (Table 16). Respondent 1 was the only pilot in this study not to hold an airline instructor position, and the achieved SA score was, in terms of the SA scores observed in this sample of pilots, noticeably less than the other three candidates.

Table 16: Situational awareness scores compared with instructor rating held.

	Situation Awareness	Instructor Rating
Respondent 1	0.81	B Cat (2)
Respondent 2	0.85	Flight Instructor (6)
Respondent 3	0.85	Training Captain (5)
Respondent 4	0.87	Flight Instructor (6)

Note: The figures in brackets (x) represent the rank number assigned to the instructor rating.

To further highlight the different experience gained by each of these pilots, it should be noted that in addition to a Flight Instructor rating Respondent 2 had also held Simulator Instructor, Training Captain and A Category instructor ratings. Furthermore, Respondent 4 had also held Simulator Training, Training Captain, A Category instructor ratings, as well as CAA examiner and Royal New Zealand Air Force (RNZAF) (A2) ratings. These additional ratings were not plotted on Figure 15 or listed in Table 16 as only the highest ranked rating, as determined appropriate for this study, was plotted for each participant.

Ab-Initio Training

Indications of the style of ab-initio training were evaluated to determine if the way in which the foundation of aviation knowledge was acquired affected SA abilities. The first indicator considered was the type of training organisation with which the individual first trained. Four options were provided for participants to indicate the type of organisation where they underwent their initial training. These options were; Aero Club, Flight School, University Course or Air Force. The sample obtained was evenly split between aero club (or general aviation) and Air Force training (Table 17). From these results no particularly strong relationship between the style of ab-initio training and SA is evident.

Table 17: Situational awareness scores compared with training organisation.

	Situation Awareness	Training Organisation
Respondent 1	0.81	Aero Club
Respondent 2	0.85	Aero Club
Respondent 3	0.85	Air Force
Respondent 4	0.87	Air Force

The duration of ab-initio training was considered to determine if the length of a pilot's initial training affected the development of knowledge structures associated with SA. To facilitate analysis of the training duration all reported training course lengths were converted to a common unit, in this case months. Table 18 shows the ab-initio course duration for each respondent after being converted to months. The training durations listed here indicate that the longer the training course the lower the achieved SA.

Table 18: Situational awareness scores compared with training duration.

	Situation Awareness	Training Duration
Respondent 1	0.81	36
Respondent 2	0.85	24
Respondent 3	0.85	10
Respondent 4	0.87	18

Plotting duration in months against SA on a scatter plot (Figure 16) visually reinforces the pattern observed in table 17. In the scatter plot the visually compelling line created by plotting the position of Respondents 1, 2 and 4 is broken only by the position of Respondent 3. However, information on the biographical information form provided by Respondent 4 reveals a varied programme of initial training for this participant. Respondent 4 initially performed the first 100 hours of flight training with an aero club, after which acceptance on an RNZAF course resulted in continued training by that organisation. For the purposes of this study, Respondent 4 was categorised as an Air Force trained pilot due to the fact that all pilot recruits for the Air Force undergo the same training programme, regardless of previous flight experience. Therefore, while Respondent 3 does not appear to fit the pattern portrayed by the other participants, the unusual programme of ab-initio training received by Respondent 4 could imply that this result is actually the anomalous value. However, the overall impression given by the

slope in figure 13 implies that, in this sample, those participants who underwent a shorter initial training course achieved higher SA scores.

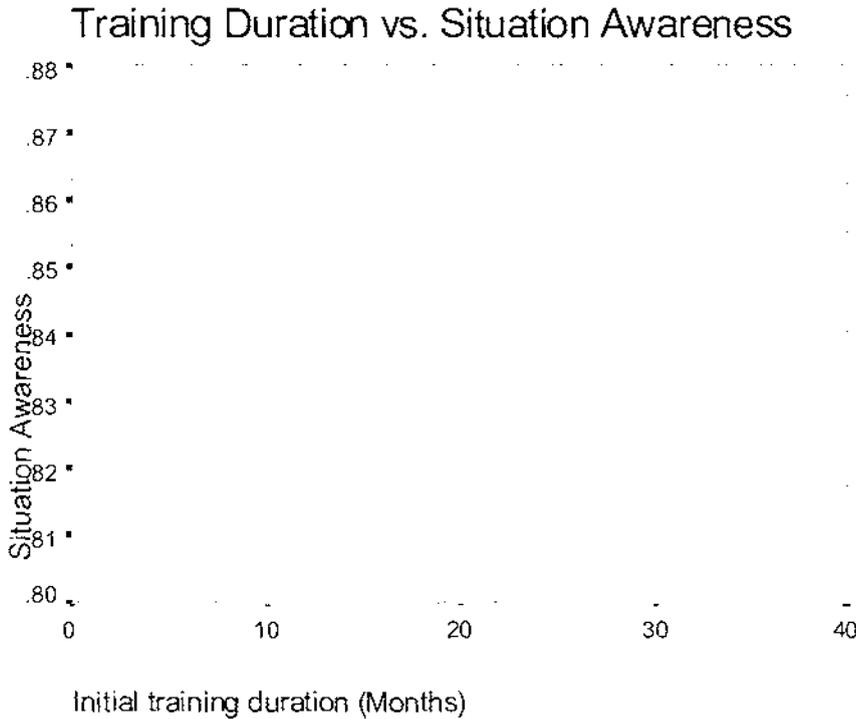


Figure 16: Scatter plot of SA score vs. Ab-initio training duration.

The final factor considered was the consistency of ab-initio training. This was evaluated by considering whether the training course was full time or casual. Table 19 shows that the candidates were evenly split between full time and casual courses. Again, similar to the analysis of training duration, the SA scores achieved by the pilots in this study tended to be higher for those who reported that their ab-initio training was full time. This is congruent with the results for training duration, as a full time course would be expected to be a course of shorter duration.

Table 19: Situational awareness scores compared with training consistency.

	Situation Awareness	Course Type
Respondent 1	0.81	Casual
Respondent 2	0.85	Casual
Respondent 3	0.85	Full Time
Respondent 4	0.87	Full Time

Viewed in isolation few compelling patterns emerge from the data to present a case for a potential benefit from any particular style of ab-initio training. However, overall each of the three measures taken reveals a consistent pattern. In this case, for the pilots that participated in this study, it would appear that those who underwent Air Force training, which is a full time relatively short duration course, achieved slightly higher SA scores.

However, the substantially lower score of Respondent 1 provides an outlier case that is in contrast to the remaining three respondents. Due to this, relative to the other SA results, the much different SA score of Respondent 1 has a proportionally large influence on analysis of the data due to the small number of cases. If for instance, Respondent 1 were removed from the scatter plot for training duration the pattern revealed would appear to be essentially random. In addition, the lower SA score recorded for this participant substantially influences the pattern implied by the data for training organisation and consistency of training. Therefore caution needs to be exercised when interpreting these results.

4.5 Summary

Exploring the data gathered from the sample of pilots obtained for this study has proved an interesting exercise. However, due to the small size of the sample there is insufficient data available to support or reject any particular hypothesis. Furthermore, there is a danger that the patterns displayed by the current findings increase the chance of identifying a spurious relationship. Despite this, two positive aspects can be drawn from the results, firstly the instruments and procedures used in this study held up well during investigation, and could be used in future studies. The only issue that needs considerable further consideration in future studies is the need to secure a larger sample of participants. Secondly, while the size of the sample does not provide sufficient support to identify any specific relationships, the data does indicate areas that could profit from future research. Of particular interest are the relationships between SA and flight instructor rating, and SA and duration of ab-initio training.

CHAPTER 5: DISCUSSION

In order to provide the following discussion with the appropriate context, it is necessary to make a short statement regarding the limitations of the sample obtained. Due to the very low number of participants involved all findings in this study are limited to the particular sample obtained, and cannot be generalised to the commercial pilot population for two primary reasons. The first and most significant of which is the small sample size, and the second is the relatively homogenous sample of pilots that volunteered for evaluation. This sample of pilots was particularly similar with regard to the flight experience each had accumulated, which may also account for the fact that virtually no meaningful relationship between SA and flight experience was observed. The similarity between the subjects, more than likely, also obscured any potential association between SA and the motivational elements measured.

In some respects it was surprising that the study did not appear to appeal to younger pilots who might be expected to have a greater interest in automation, and computerisation issues. However, after speaking to the pilots who did participate in this study, it became evident that they were interested in this area due to FMS shortcomings that they have observed. It would therefore appear that the additional experience that these pilots had gained lead them to develop an interest in the impact automated systems have on the piloting role. Further consideration regarding the poor response rate will follow the discussion, but for now, the results obtained will be discussed in terms of this sample of experienced pilots.

5.1 Test Procedure

While it is not possible to reach any firm conclusions, or to generalise findings to the population due to the small sample size, the results obtained do support the validity of the test procedure. Endsley (1995a) performed a series of tests using the SAGAT procedure to evaluate its validity. From these tests Endsley found that stopping a simulated task during execution to administer queries was a valid method to obtain information from subjects. In particular, these tests identified that the freeze technique was not unduly intrusive on task execution, and that valid information could be obtained

from subjects for up to 5 or 6 minutes after a simulation freeze (Endsley, 1995a). The results from this study support Endsley (1995a) findings.

The random query selection did achieve a reasonably even distribution of administrations for each query while not displaying a single line of questioning to the participants. Support for this can be found in the similar proportion of queries administered, for Level of SA and query focus, in comparison with the number of queries in each category in the query database. Therefore, a relatively balanced view of the participant's knowledge was gained.

The consistency with which participants answered queries during each simulation stop supports the finding that simulator freezes do not appear to unduly inhibit the participant's performance of the primary task. This holds even though separate computers were used for the simulation task and query administrations in this study. Furthermore, the consistent response rate displayed by each participant during SAGAT stops supports the validity of information gathered during query administration. Overall, the data obtained during testing for this study supports the validity of the SAGAT procedure to collect information on subject SA, provided the appropriate guidelines are followed.

5.2 Situation Awareness

5.2.1 Perfect Situation Awareness?

One of the most striking results evident in this sample of pilots is the very close grouping of SA scores. The range of correct answers was between 81% and 87%, a spread of only 6%. While this indicates that all participants achieved a reasonably high correct response rate, these scores are less than perfect, and therefore represent less than perfect SA of the environment.

The level of SA required to operate effectively in a complex dynamic environment has not yet been established (Endsley, 1995a). Obviously perfect SA, or 100% correct understanding of an environment, would most likely provide the greatest opportunity for achieving successful performance. However, it is not known if an operator can still achieve an adequate level of performance, on a consistent basis, with less than perfect

SA. In this respect an interesting observation can be made for this group of pilots in light of the flight experience each had gained.

In the context of commercial aviation experience all of the participants in this study would be considered very experienced. All were senior Captains on wide-body aircraft flying international operations with a world-class airline (Hanlon, 1999). Consequently, they would have undergone and passed numerous flight and simulator proficiency checks during their careers. As a result, within the aviation industry these pilots would be regarded as subject matter experts in the field of commercial jet transport aircraft operation. Therefore, the high level of experience possessed by these pilots should, in theory (Dingus et al., 1997; Endsley & Bolstad, 1994), have enabled them to attain high levels of SA required to achieve consistent proficient performance. In terms of the SA scores recorded in this study, it would appear that 80% to 90% correct SA was sufficient for this group of pilots to manage a novel FMS simulator to achieve the desired goal, in this case to fly from one point to another. As a result of this observation, future studies could test the hypothesis that 100% SA is not required to operate FMS equipped aircraft.

Small Range Of Scores

It has been highlighted that the range of SA scores observed was very narrow. The reason for this similarity cannot be determined from the limited sample obtained, however, three possible factors could be at work. Firstly the SA scores recorded could represent the existence of a maximum level of SA for the use of a novel system, secondly the similar experience accumulated by these pilots could explain the grouping of SA scores, and third such a grouping may have resulted from low workload.

It is possible that the SA scores do not show a great deal of variation due a ceiling, or maximum possible score, for the testing conditions. Because none of the participants had any experience with the particular FMS system used during testing, they all needed to learn and adapt to the system. Obstacles to achieving SA would have been present from the start of the SA process. Due to the unfamiliar design of the simulator interface, participants would likely experience problems finding the information they needed because of differences in system operation and feedback (Abbott et al., 1996). As a result, an impediment to commencing the development of higher levels of SA is present

from the outset. Furthermore, the different system operation would require the participants to process more information in working memory, as existing mental models for other aircraft FMS could not be applied directly to the simulator system. Instead they had to learn how to navigate the FMC menu structure before any action could be executed (Adelman, Cohen, Bresnick, Chinnis Jr, & Laskey, 1993). In combination these factors would increase working memory processing demands, possibly reducing capacity to process all elements that would normally be considered when using a familiar system with long term memory stores working in the pilot's favour. Therefore, the grouping of SA scores observed could represent the effect of an SA ceiling, or maximum possible score, for this group of pilots while operating an unfamiliar system. Consequently, it is possible that higher SA scores might be recorded when operating a familiar system.

Related to the idea of an SA ceiling, is the possibility that the very similar level of experience possessed by this group of pilots influenced the SA scores. In this case the lack of any consistent trend between SA and flight experience found here, in contrast to previous findings supporting the benefits of experience on SA (Dingus et al., 1997; Endsley & Bolstad, 1994), might have been due to the similar level of experience possessed by participants. The homogenous sample, in combination with the very low number of cases, results in insufficient data to determine what relationship might exist between SA and experience for these pilots. Further testing with a larger sample is needed to determine the direction, and strength, of the relationship between experience and SA.

A third possible cause for the grouping of SA scores observed could be low workload. Endsley (1993) found that while SA and workload may interact with each other, they can also vary independently of each other. As such, there are certain conditions that create high workload which may lead to low SA, and conditions of low workload that might allow high SA to be achieved. It should also be noted that maintaining SA is not the only process requiring the individual's attention, and the individual's total cognitive workload is also affected by decision-making and action taking demands required by the situation. Therefore, if the participant's workload during the test flights was low, this may have allowed participants to attain higher levels of SA, leading to the grouping of SA scores observed.

However, workload was not measured in this study, and the only indications available that can be used to gauge participant workload come from implications of the flight schedule and the participant's actions. The short duration of all the flights undertaken during evaluation required the participants to perform all normal flight duties in a constrained time frame. In combination with an unfamiliar FMS interface, which would require greater time and effort to operate (Adelman et al., 1993), it would be expected that a moderate workload would result. Some support for this was evident during the evaluation sessions as the participants were observed to maintain a reasonably constant level of activity throughout each flight. Therefore, while no quantitative effort to measure workload was made, it seems likely that participants were exposed to a moderate workload during testing. Consequently, the similar SA scores observed in this study could arise from participants being exposed to only a moderate workload allowing them to achieve optimum SA. A greater spread of SA results could possibly have been observed if participant's workload had been increased during testing (Endsley, 1993; Endsley, 1995b). However, the extent to which low workload may have affected SA scores, and the direction of that affect, cannot be determined from the data, as workload was not measured.

To test the impact that workload may have had on the grouping of SA scores would require further testing with more control over workload. Increases in workload without introducing artificial tasks could be achieved by using higher fidelity simulation. Doing so would allow all normal flight activities, such as the use of correct air traffic control procedures, fuel management, pressurisation monitoring and control of other aircraft systems to be introduced. In this way a more accurate picture of SA in the normal environment would be gained in comparison to introducing irrelevant tasks merely designed to increase workload. However, there are drawbacks to the use of high fidelity simulators, the most significant of which are availability and cost.

5.2.2 Distribution of Situation Awareness

The break down of overall SA scores into scores for Level of SA and the query focus, primary data vs. FMS information, showed an interesting effect. Firstly, correct answers were given to questions relating to the higher levels of the SA process more often,

implying that these pilots had a greater understanding of the integrated comprehension and appreciation for future demands of the situation, than the values of specific parameters. Secondly, the percent of queries relating to the FMS that were answered correctly, was well above that for primary data.

The Levels of Situation Awareness

Comparing the percentage of queries that were answered correctly at each level of the SA process reveals a relatively consistent picture. In this sample the percent of queries that were answered correctly increased by 7% as the level of SA increased. This pattern implies that the pilots who participated in this study were able to build on the preceding levels of the SA process reasonably effectively. This indicates that comprehension of the situation and anticipation of future demands may have been aspects that these pilots considered more important than precise knowledge of environmental values. Potentially, the objective driving the focus on higher levels of understanding amongst these pilots, who were all experienced aviators, could have been the desire to performing strategic flight planning. To achieve this objective the participants would require a greater understanding of the higher levels of the SA process, and in particular level 3. However the significance of the 7% increase is difficult to determine from these results, and further testing is required to determine whether this increase is chance or an actual improvement in understanding.

SA theory as discussed, states that the levels in the SA process are sequential, and that the understanding generated from lower levels is used as the basis for developing an understanding at the next level of SA (Endsley, 1995b). Accordingly, development of the highest level of SA is dependent on proper understanding of the environment at the preceding levels. Therefore, while it might initially appear contrary to SA theory that understanding associated with a higher level of SA can exceed the preceding level, this may not necessarily be a limitation to an experienced operator. It is possible that application of mental models with appropriate default values, and the use of estimation techniques, can be used to fill-in holes that might exist in the understanding possessed of a lower SA level (Endsley, 1995b). However, as a consequence of using defaults and estimations, the accuracy of knowledge for specific environmental parameters would be reduced, causing a corresponding reduction in the accuracy of Level 1 SA. This is a tendency that was noticed in the results for this group of pilots. Despite the reduced

accuracy of Level 1 SA, the use of defaults and estimations will allow the individual to generate a substantially complete “perception” of the environment, permitting a reasonably accurate comprehension and anticipation of the situation. In this way it is possible that an improvement in understanding from one SA level to the next could occur. It will be apparent that only an experienced operator will have developed adequate default values and estimation techniques. Therefore, it is possible that the improvement from one SA level to the next observed in this sample of pilots resulted from the application of their considerable flight experience. As indicated the participants in this study were observed to make comments that implied the use of both mental models and estimation techniques, which may have led to improved SA at higher levels. However, despite what might be possible according to theory, evidence to support such a hypothesis is certainly needed. Therefore, if the prospect that SA can improve as the level of SA increases is to be tested further, it would appear important to use a mix of experienced and inexperienced operators.

The Focus of Situation Awareness

The large difference in the percent of correctly answered queries between FMS and primary data questions points to a substantial shift in attention for these pilots. The tendency to focus attention on FMS elements in the simulation is re-enforced by the relatively similar difference in correct response rate between FMS and primary data queries for each participant. In this case, all participants made fewer errors when responding to FMS related queries than when answering primary data queries. This presents a relatively strong case for the proposition that the FMS dominated the pilot’s attention to the situation within this group of participants. Such a shift in attention improved their FMS related understanding, but came at the cost of reduced appreciation for primary data.

It should be noted that the difference in correct answer rate for FMS and primary queries does not appear to be indicative of a narrowing of attention. In general, the primary information queries that were answered incorrectly often did not fall outside of the acceptable range by a significant amount. Therefore, it would appear that primary data was being scanned less frequently, reducing the currency or accuracy of this knowledge. This implies that the participants in this study were not becoming fixated on FMS management at the cost of everything else. In effect, demonstrating that while this

group of pilots may have directed more attention to the FMS, they did not get drawn into cognitive tunnelling (Endsley, 1995b; Woods et al., 1987) as a result. Despite this, the reduced accuracy of primary information knowledge may suggest that the nature of SA for FMS and primary data would be worth further investigation.

The potential causes for this group of pilots to focus their attention on the FMS might be explained by the pilot's role in the system, and factors relating to the evaluation procedure. An issue of particular interest is the impact that the pilot's role as supervisory manager of the system could have on allocation of attention.

Operation of FMS

As discussed, one of the consequences of introducing FMS into aircraft has been a change in the nature of the tasks the pilot is expected to perform. This change has taken the form of placing the pilot in a management role, removed from the integral flight control loop. Consequently, as the task of performing flight manoeuvres is assumed by the FMS, specific flight parameters are no longer as significant to the pilot. As long as the pilot has a sufficiently accurate appreciation for the aircraft's position to allow strategic flight planning to take place, the aircraft can be operated normally without attending closely to primary data. This change in operating role, and the fact that the pilot is now expected to interact with the FMS rather than the aircraft flight controls, means the pilot needs to focus on those elements significant to FMS operation. In this way FMS settings and targets take on greater significance to the pilot than exact knowledge of primary flight parameters. However, the pilot's awareness of primary flight data needs to be accurate enough for the pilot to know that FMS targets have not already been exceeded, otherwise there is a risk that a flight path excursion could occur (Palmer, 1995). For example, if the pilot's knowledge of primary information is too coarse there is a risk that the aircraft may pass a flight target before the pilot has engaged the system to capture the target parameter. In this case the FMS will continue to fly the aircraft without regard for what the pilot was trying to achieve, and continue to fly further from the intended flight profile. As the density of commercial air traffic continues to increase (ICAO, 1999), greater accuracy is required during all phases of flight. It is therefore important that the pilot maintains an awareness of primary flight data to verify that the intended performance is being achieved (Palmer, 1995).

The need to monitor both FMS and primary information has effectively increased the pilots monitoring demands. Therefore while a reduction in physical workload may have occurred due to the introduction of FMS, there has been a veritable explosion of cognitive demands (Abbott et al., 1996; Kantowitz & Casper, 1988). This presents challenges for the design of FMS interfaces to assist the pilot cope with the increasing monitoring demands. One option to assist the pilot is for the system to become more agent-like in its operation (Hoc & Lemoine, 1998), rather than the current robot style function of most FMS. This supports the human centred design philosophy (Billings, 1991a; Emerson & Reising, 1991; Endsley, 1995c). One proposal made by Billings (1991a) recommends that objectives be shared between the FMS and the operator. If this were done the FMS could critically evaluate what the pilot is requesting in comparison with the set objective, and alert the crew if a disparity occurs. Continuing the example from above, the crew could be informed that the target they have set has already been exceeded and another action is required. Current FMS already incorporate one function that takes a step toward a sharing of objectives; this is the “Direct To” function. The “Direct To” facility allows the pilot to tell the aircraft to fly from the present position directly to any navigation waypoint. When the pilot uses this function the current objective is inherent in the instruction given to the system. In this case both the pilot and system have the same objective, to fly in a straight line from where they might be to another known location. Assuming the correct waypoint is selected, and barring any abnormalities, there is virtually no possibility that FMS will fail to achieve the set objective. However, determining the next waypoint is a relatively short-term objective and does not allow the system to consider if the chosen waypoint is appropriate or not. Objectives that provide a more distant time horizon (Scijts, 1998) need to be established to provide the FMS with the capacity to evaluate the suitability of pilot selected modes. Such objectives might be that the pilot wishes to land on a particular runway using a specific approach aid. This type of objective would, for example, enable the FMS to determine that the approach mode was armed after the aircraft passed through the final approach course, and could therefore notify the pilot that the objective will not be fulfilled. If an event such as this occurs in current FMS equipped aircraft, the FMS will continue to fly the aircraft further away from the approach course, and it is entirely up to the pilot to resolve the situation.

However, careful consideration needs to be given to how, and which objectives, are shared between the pilot and FMS to avoid further increasing pilot workload during departure and approach phases of flight. The highly dynamic nature of objectives during these flight phases' means that continually updating the FMS objective will only further distract the pilot from the task of ensuring the aircraft is flown properly. Increasing workload during phases of flight that are already very busy is a problem that current FMS already face (Billings, 1991b), and any changes should be aimed at alleviating not aggravating this problem.

Knowledge of Evaluation

It is recognised that subjects participating in a test procedure can be artificially cued to direct more attention to certain aspects of the procedure than would be normal for execution of the task. One factor that can cause such a tendency is the participant's knowledge of the test focus (Endsley, 1995a). In this study participants were aware that the subject of interest was the human-machine interaction with the FMS. As a result participants may have directed more attention to working with the FMS than normal. However, while participants were aware that the evaluation intended to investigate pilot-automation interaction, they were not told that their SA of the FMS was to be measured. Therefore, it is not likely that participants would have been worried about maximising their SA scores, as the emphasis for the testing was placed on the automation. Consequently, the influence this effect may have had on the results should have been minimal.

Intention to Use

The disparity in correct response rate between FMS and primary data queries could also have been influenced by the participant's intention to use the FMS. Despite the fact that participants were told that the study related to human-machine interaction with regard to the FMS, their perception of FMS would still moderate their focus on the system. Information systems research has found that an individual's intention to use a system, which directly affects their usage behaviour (Agarwal, Prasad, & Zanino, 1996; Davis, Bagozzi, & Warshaw, 1989), is affected by their perception of the system. Specifically, the perceived usefulness, which is "the degree to which an individual believes that using a particular system would enhance his or her job performance" (Moore & Benbasat, 1991, p.197), has been identified as a substantial factor contributing to information

systems usage behaviour (Davis et al., 1989). It is likely that there was a high perceived usefulness of FMS amongst these pilot considering their interest in participation in the study, and the exposure to the use of the system in the aircraft. Correspondingly, this perception may have translated to a greater intention to use, and consequently high usage behaviour of the FMS, which could have influenced the tendency to focus more attention on the FMS as identified in the results.

The Simulator Displays

Another influencing factor that may have reduced the correct response rate to primary data queries could have been the size of the primary flight data displays in the simulator. In all cases these displays were not easy to read and could not be enlarged, unlike other display panels, to more easily determine their values. As a result, the accuracy of the participants primary data knowledge may have been reduced due to interpretation difficulties.

5.3 Situation Awareness and Motivation

Measurement of motivational factors was undertaken in this study in an attempt to determine whether an individual's internal drive to achieve certain objectives influences their SA. The results gathered for each of the motivational factors evaluated (assertiveness erg, fear erg and career sentiment) do not suggest that the SA scores for these pilots were affected in any consistent manner by their level of motivation. In isolation, the results for each of the motivational factors measured displayed a fairly random association with SA.

Taking a more holistic approach, one result does stand out. Respondent 2 displayed quite different levels of motivation to the remaining 3 participants for both the assertiveness erg and career sentiment. In particular, the level of assertiveness erg displayed by Respondent 2 was quite high, in stark contrast to the other candidates who all displayed an assertiveness score of 1. The difference in career sentiment for Respondent 2 was not as dramatic as for assertiveness, but none the less was markedly lower than the other participants. These results are particularly interesting in light of the SA score and level of flight experienced Respondent 2 had gained. Respondent 2 was the most experienced candidate, in terms of flight hours, and correspondingly according

to SA theory (Endsley, 1995b) and research (Carretta et al., 1996; Endsley & Bolstad, 1994), should have been able to achieve a level of SA higher than the other, less experienced, participants. Despite that, the SA score achieved by Respondent 2 was only equivalent to the mean for this group. Therefore, a possible implication is that the different levels of motivation displayed by Respondent 2 may have affected the SA score. In this case, the inference might be made that, for the testing conditions, low career sentiment and high assertiveness did not promote the most conducive state to develop the best SA. However, the implication evident in the motivational scores for Respondent 2 is not strong, and even if a person's combined level of motivation affects SA the affect may only be weak.

Although the motivational factors chosen did not display any consistent relationship with SA, there may still be merit in determining whether motivation or level of psychological arousal influences SA. However, from these results it is difficult to determine which motivational factors would likely influence SA and are worthy of pursuing. The observation was made that there may have been some association between assertiveness and career sentiment that could have affected Respondent 2's SA score. Therefore, future investigations of these motivational factors might be warranted. However, the observation made here is based on one case, and cannot suggest the presence of any relationship beyond this sample.

5.4 Situation Awareness and Experience

5.4.1 Flight Experience and Situation Awareness

Accumulated Flight Hours

Contrary to the findings of previous research (Carretta et al., 1996; Endsley & Bolstad, 1994) very little relationship between SA and flight experience was evident in the sample of pilots who participated in this study. Rather than pointing to no association between accumulated flight hours and SA, this further highlights the limitations of the sample gathered. It is more than likely that no significant relationship with flight hours and SA was evident due to the very homogenous sample of pilots who volunteered to participate in the study. The range of flight hours exhibited by the volunteers was relatively small, providing very little variation in flight hours for any trend with SA to emerge.

Aircraft Type Ratings Gained

To consider flight experience from a slightly different perspective the number of type ratings gained were evaluated. Type ratings were used as a qualitative indicator of flight experience and training to which each participant had been exposed. In order to gain a type rating for an aircraft the pilot must undergo a type rating conversion course. Each rating covers aircraft handling and systems knowledge, including the use of the aircraft's autopilot or FMS. Consequently, the more ratings each pilot has gained, the greater the exposure to formal instruction on system operation that person would have received. This is likely to lead to development of more accurate mental models and schemata for aircraft handling and the operation of advanced flight systems.

The analysis of type ratings against SA in this sample only mildly supports such a possibility. The overall trend for the total number of ratings held by each pilot displays a slight positive relationship in relation to SA. However when considering the number of cases involved, and the contrasting SA score of Respondent 1, the importance of this tendency within the sample gathered is not strong. One difference that is noticeable within the sample is the type ratings that Respondent 4 reported. In this case all 6 of the aircraft flown by Respondent 4 were swept wing turbo-jet aircraft. This differs considerably from the remaining participants who only reported 2 or 3 ratings for such aircraft. While it should be noted that not all of the aircraft Respondent 4 had gained ratings for would have had FMS, these aircraft would expose the pilot to the management of semi-automatic, and fully automatic, aircraft systems. In addition, all of these aircraft would at least have had a basic autopilot system. Consequently, the training in the use of these systems may have promoted a better understanding of the application of automated systems. In turn, this may have contributed to the higher SA score achieved by this participant in light of the average flight experience accumulated in the context of this group of pilots. However, the importance of this benefit is not strongly supported by the results of the remaining three participants. The pattern within these three remains random even when considering only the swept wing turbo-jet aircraft type ratings. This signals that what benefit, if any, that might be gained from undergoing aircraft type rating courses might only be weak.

5.4.2 Instructor Ratings and Situation Awareness

The results from this study suggest that a relationship between instructor rating and SA might exist within this group of pilots. The relationship identified points to a benefit to SA from holding the highest instructor ratings, as defined in this study. Potentially, the cause of this observed tendency in this sample could be a consequence of the better mental models and understanding of FMS operating philosophy possessed by the airline instructors.

Deep Learning

The most striking observation from the instructor rating vs. SA plot is the position of Respondent 1. In this situation Respondent 1 stands out as possessing noticeably different instructor experience to the remaining participants. Most strikingly Respondent 1 is the only participant not to hold an airline instructor position. It is therefore possible that the difference in SA score between Respondent 1 and the other three participants is due to a benefit that the three airline instructors gained from their instructor roles. Instructional research has demonstrated that the act of preparing to teach produces a more highly organised cognitive structure. Actively reorganising the material allows “the teacher to see the issue from new perspectives, enabling him/her to see previously unthought-of new relationships between the discrete elements. It may be this building of new relationships that facilitates a better grasp of the material” (Bargh & Schul, 1990, p595). This being the case all three airline instructors are more likely to have robust knowledge structures (or mental models) for the systems they normally use, and a better understanding of FMS operating philosophies. The development of these improved knowledge structures would be necessary for the airline instructors to teach other users, who would probably be of various levels of competency, how to employ the system effectively. Conversely, Respondent 1 would have no need to develop such an advanced understanding of FMS, as the instructor rating held by this participant did not require teaching the use of management systems. Therefore, the rationalisation of FMS related knowledge undertaken by airline instructors to facilitate teaching system operation, might account for a substantial proportion of the difference between the airline and non-airline instructor SA scores.

Observation Role

Another potential cause for the difference in SA observed between the instructor positions could arise from the airline instructor role. Part of the instructor's role is to monitor the performance of their students, including operation of FMS. Arising from personal experience observing other pilots operating FMS this researcher found it possible to follow system changes, and consequently understand the operation of system modes, even when the pilot flying was obviously confused or surprised by the systems actions. Consequently, when considering the higher SA score of the airline instructors in this group, and the nature of the instructor's role, it is possible that the opportunity to observe system operation may promote development of better schemata and lead to greater refinement of mental models. These refinements may be made possible due to observation of various operating techniques and, observation of system operation in non-normal situations.

From the results chapter it will be noted that, at some stage, all three airline instructors had held Training Captain ratings, and two were currently Flight Instructors. In the role of Training Captain or Flight Instructor the individual will observe and instruct many pilots undergoing conversion training to various aircraft types. This includes pilots new to FMS aircraft, and pilots who may have flown several FMS equipped aircraft. Consequently, these instructors will observe both very good and very bad operating techniques. It has been observed that operators who do not properly understand system operation will not use available modes appropriately, and may only utilise a limited number of modes they understand to achieve all flight manoeuvres (Sarter & Woods, 1995). The limitations of these operating techniques will become apparent in comparison with highly proficient operators that use a greater number of modes in different situations. Consequently, by observing a wide range of operating techniques the merits and limitations of particular operating methods will become apparent (Fletcher et al., 1997). This becomes important as, in some flight scenarios, the automation provides several ways to achieve the desired objective. However, depending on the situation one method might be more appropriate than another (Parasuraman & Riley, 1997). For example, when on descent below 10,000 feet the aircraft is rapidly approaching the final approach to land segment of the flight, which might only take 3 or 4 minutes to complete. However, in this time the aircraft must be slowed and configured for the approach, while at the same time several course changes and descent profile

changes might be required. To comply with the necessary course changes and flight profile management the FMC or standard autopilot modes can be used. Of these two options using the FMC will present the most significant limitations due to the time needed to programme the course changes (Lintern, Waite, & Talleur, 1999). A simpler option is to use only standard autopilot modes that require much less time to effect a change in flight path. The limitation with standard autopilot modes is that the pilot must then calculate and monitor the flight path manually, which create an increase in cognitive workload. However, by doing so their SA of the aircraft's location and status will probably be enhanced, increasing the likelihood of good performance. Such differences in operating technique, and the consequences of those techniques, would be observed by Training Captains and Flight Instructors more often allowing them to refine their models of system operation to a greater extent.

Extending this concept further, a note should also be made regarding the Simulator Instructor role. Two of the three airline instructors had also been Simulator Instructors. Simulator Instructors are afforded the opportunity to observe FMS operation in extreme circumstances. During periodic simulator checks crews are expected to demonstrate aircraft operation in non-normal and emergency conditions. This presents the Simulator Instructor with the opportunity to observe infrequently executed manoeuvres from a neutral position. As a result the Simulator Instructor will be able to track system changes during these manoeuvres, allowing them to develop a more comprehensive model of FMS logic. Poor knowledge of infrequently used modes is a weakness highlighted by Sarter and Woods (1994). However, the crew performing the simulation will not be afforded such luxury, as they will be under a high workload while dealing with other system management functions. Consequently they may not be able to track all system changes, and will not be able to refine their mental models in light of how the system functioned in that situation. Instead they will be left with the problem of how to recover from the situation in which they "find themselves".

Consequently, it is the impartial observation role that may allow the airline instructors to learn more about system function than can be acquired through flight experience when operating as part of the active crew with other workload demands. Therefore, it is possible that allowing all pilots to observe transitions between infrequently used modes, and how the system functions during unusual manoeuvres, could enhance FMS SA

(Hunt, 1997). This is not to say that all pilots should merely sit and watch others perform flights, as this would probably result in excessive boredom and it is likely that no advantage would be gained. Instead, flight exercises should be set that specifically focus on FMS operation, without introducing the additional load of system abnormalities to allow the crew to observe how the system deals with the situation.

In effect the aim of this concept is to avoid building inert knowledge of the system (Sarter & Woods, 1992), which can occur from abstract rote learning of what each system does in isolation. Further testing would need to be done to determine if there are any beneficial effects from such a practice, however, if there are it would represent a feasible basis on which an FMS training scheme could be built.

5.4.3 Ab-initio Training and Situation Awareness

Duration of Training

Of the ab-initio training indicators gathered, only the duration of training displayed a pattern of any note. Within the sample of participants gathered it appears that those who underwent a relatively short initial training programme achieved better SA scores. Some support for this tendency is also provided by the comparison of full time vs. casual training course. As might be expected, a full time course would complete an initial flight training programme in a shorter period. Therefore, the results from these two indicators are in agreement. However, the strength of the relationship between full time and casual courses was not very strong, and therefore the support for the benefit of shorter training courses needs to be viewed accordingly.

While a very distinctive line is present in the plot of training duration against SA, Respondent 4 again represents a unique case. Consideration of additional information provided on the biographical information form brings into question the actual reason why Respondent 4 fits the line so well. Rather than the high SA observed being associated with the benefit of a short course, it is possible that Respondent 4 benefited from a varied ab-initio training programme. As opposed to the other three candidates, Respondent 4 performed the first 100 hours of flight training with an aero club before joining the Air Force. Because all Air Force candidates are required to complete the entire initial flight training programme regardless of prior experience, this would result

in Respondent 4 receiving training on basic flight knowledge and skills from both the aero club and Air Force perspectives. Therefore, it is possible that this duplication of initial training may have resulted in a better foundation of aviation knowledge enhancing the respondent's ability to achieve high SA. This dual training aspect may be more significant than a simple relationship between course length and SA, and signals a cautionary note to attaching any meaning to this pattern.

Overall Ab-initio Perspective

Despite the limitations exposed by the consideration for course duration, an observation regarding this group of pilots can be made. Taking a holistic view of the trends displayed by all three indicators, training organisation, training duration and full time vs. casual course, a consistent picture is revealed. This picture shows a pattern that points to a consistency in training being beneficial to SA skills. In the sample of pilots obtained those that undertook Air Force training, which is a full time programme over a relatively short duration, achieved higher SA scores. However, this observation is limited to the current sample of pilots, and does not establish any particular ab-initio training regime as promoting SA skills. Taking this into consideration, the overall pattern observed does provide an indication that the ab-initio training a pilot receives may influence their SA abilities. Consequently, future studies investigating this concept further may uncover important relationships between initial training and SA abilities relevant to flight trainers.

5.4.4 Role of Schemata & Mental Models

As indicated in the results, it was evident that the participants were applying schemata and trying to adapt mental models to assist them operate the GNS-XIs simulator. Evidence to suggest that the participants were trying to adapt mental models to the simulation came from statements the participants made during testing. The participants were often observed to make comments to the effect "if this works as it does in the aircraft then I would expect..." Such statements imply that the participants were trying to adapt mental models for specific aircraft FMS to the GNS-XIs simulator.

Another observation regarding the participants operating techniques, and its implications for mental models, can be made from the pilot's actions during the

simulated flights. On several occasions participants used a formula, or a rule of thumb, to calculate answers to SAGAT queries. This reflects an additional level of complexity in the associations and default values contained in the mental model. In addition to providing functional associations between environmental elements, it appears that mental models may also include precise mathematical associations between those elements (i.e. formula). This allows calculation of variable information for which no default value can exist. The mental model therefore has, as part of its structure, the formula for calculating the value of environmental parameters from other known values, or combinations of environmental values and default values. This is exemplified by the technique participants used to estimate the aircraft's altitude when only the distance to the next target waypoint defining an altitude restriction was known. To achieve this calculation the participants used a general rule of thumb for calculating distance required to descend through a set amount of altitude. In this case the formula states that to descend 300 feet a pressurised aircraft will travel 1 nautical mile. Therefore, by working this formula in reverse using the distance to run, the height above the target altitude for the waypoint can be calculated. By adding the target altitude to the height above the target, the aircraft altitude can be estimated and the query answered even though the actual value was not available from memory.

In the actual aircraft there is, of course, no reason to perform this calculation to answer an artificial query, as it would be much simpler to read the value from the altimeter. However, this formula would have been learnt as a means to approximate the top of descent point, and estimate the descent profile. Using a formula such as this also provides the pilot with an invaluable tool to cross check the validity of new information that is received. This is particularly important to establish if a new piece of data, or the result of a system setting, is congruent with their understanding of the situation. If the new information can be roughly checked for accuracy the pilot is in a position to determine whether the information is reasonable, or whether the last system change was appropriate. If not, the change can be revisited to determine whether an error may have occurred. This cross checking enables the pilot to establish a confidence level associated with the new information, in turn affecting the reliance they place on that information when developing their SA (Endsley, 1995b). In addition, such formulas allow the pilot to develop accurate predictions of ideal performance. For example, using comparisons

of achieved performance and ideal performance the pilot can project the aircraft's descent profile, enhancing their Level 3 SA.

This method of applying formula to calculate values is not, however, as efficient as the default values that can be retrieved as part of a mental model. Only the formula aspect of the relationship will reside in long-term memory and any application of the formula to the situation will require manipulation in working memory. Therefore, an additional load will be placed on working memory to determine the result, which could mean these calculations can't be performed if workload is already high.

5.5 Level of Automation

While no attempt was made to evaluate whether SA is influenced by LOA in the current procedure, discussion with the pilots that took part in the study revealed a concern over excessive "heads down" time in the cockpit. Heads down time refers to the amount of time a crew member, or both crew members, spend focused on one task inside the cockpit at the expense of the wider situation. This phenomenon is punctuated by the crew diligently working with their heads down inside the cockpit, and at the same time failing to observe primary flight displays or the view out of the window. The crash of Eastern Airlines Flight 401 in the Florida Everglades demonstrates the potentially fatal consequences of failing to observe the situation external to the cockpit. In this accident all flight crew members become involved in solving a problem with the landing gear, and failed to notice the subsequent loss of altitude that resulted in the aircraft crashing in the everglades with fatal results (NTSB, 1972). However, under normal operating conditions re-programming the FMC presents the most frequent reason for a crew member to become involved with one activity inside the cockpit. Relative to most other cockpit activities the time required to change the FMC programme is considerable. In addition, operating the FMC requires focused attention to navigate the menu structure and work within the logic of the system to programme the desired flight path (Billings, 1991b; Ricks, Jonsson, & Rogers, 1994). As a result the task of re-programming the FMC will consume virtually all of the pilot's attention for a sustained period, which may adversely affected their global SA. The pilots that participated in this study, whom this was discussed with, considered the tendency for automation to require all of the pilot's attention detrimental to the primary task of flying the aircraft.

Previous discussion dealt with the tendency for the participants to focus on FMS information to the detriment of primary data. This trend also supports the proposition that the automation tends to dominate that pilot's workload. Consequently, it would be reasonable to say that more attention is probably being directed toward the FMS and its operation, drawing the pilot's attention inside the cockpit. Due to the fact that the pilot's attentional resources are limited (Fracker, 1989), if the pilot's attention is increasingly consumed by onboard systems, less attention can be directed to external elements such as altitude, traffic or terrain. This is a tendency that is supported by the relatively lower number of correct responses to primary queries evident in the participant's SA scores in this study. This effect of automation, and the increased system complexity, contributes to the "heads down" phenomenon. Therefore greater use of the highest levels of automation at all times might not be the most appropriate means to operate the aircraft. Primarily, this is due to the time required to interact with more advanced systems in a high paced dynamic environment. In light of this information further investigation into the impact automation has on SA is warranted.

5.6 Limitations

Obtaining Adequate Sample Size

The poor response rate from pilots to participate in this study, and the limitations imposed by the small sample, have been mentioned throughout the preceding chapters. Looking beyond the restrictions imposed on the current study, the lack of response has wider implications for the evaluation of SA in general. As mentioned, even though most of the pilots spoken to regarding participation in the project agreed that SA in current glass cockpit aircraft is a significant issue, few were motivated to participate. Various reasons, including the time needed to complete the test procedure, and available scheduled days off have been offered for this low response rate. However, for whatever reason, the lack of enthusiasm demonstrated by the pilot community approached to participate in this study is concerning. If an appropriate incentive can't be found to motivate active cockpit crews to participate in SA research little valuable data can be gathered.

However, finding an appropriate incentive could prove to be a difficult prospect, as most airline pilots would be highly trained and adequately remunerated. Therefore, it is likely that the prospect of participating in an academic study would be perceived as providing little individual benefit. Overcoming this perception could present a significant problem. Two primary methods could be used to increase intrinsic value of participation to pilots. First, and most basic, would be to offer a financial reward for participation. However, the reward offered would probably need to be of a substantial amount to achieve any significant increase in response rate. In reality the financial backing required would then be difficult to justify.

Alternatively, participation in testing could offer SA skills training as an incentive. In this case the training offered would have to generate tangible skills, which the individual can observe a direct benefit of applying. Such benefit could be hard to achieve, and might require a considerable amount of the researchers time per candidate. However, some form of training benefit remains the most viable option. To use such an incentive, airline endorsement for performing SA testing as part of the normal simulation proficiency checks presents the most practical method to implement SA evaluations. By performing SA evaluation during scheduled simulator checks the evaluations would not impinge on the pilot's free time, also removing another perceived barrier to participation. The airline would benefit from this practice through the provision of quantitative data on the SA skills of their pilots. Consequently the airline would be able to identify possible areas of SA weakness, and implement additional training to address those areas. In this way the problem of low response rate can be addressed, while at the same time generating valuable data for future SA skill development.

Limitations of the Instruments

In this procedure SA scores may have been influenced by limitations inherent to the SA queries. Due to the generic nature of the GNS-XIs system, and the low system knowledge that the participants were likely to have of the system, the SA queries used did not probe very deeply into system operation. In general, the queries only related to the modes participants would be likely to use during execution of the test flights, and other fundamental operating logic. Due to the experience possessed by the pilots in this sample, querying knowledge of commonly used FMS functions probably did not

present a significant challenge. Even when the queries were situation specific, extrapolations from knowledge structures for a familiar aircraft system would allow them to answer queries reasonably accurately. For example, one of the queries asked if the aircraft would automatically descend at the top of descent point. Before the FMS can automatically fly a descent the FMC must first be programmed for the descent, the target altitude must be set and the FMC descent mode must be armed to capture the descent profile. These requirements are the same for both the real aircraft as for the simulator. Therefore, even though the specific interface and situation may be different, by working from this fundamental logic the relevant information can be recalled that allows the participant to determine if the aircraft will automatically descend at the top of descent point. In this way the relative simplicity of SAGAT queries could account for the high correct response rate for FMS related queries. Due to this limitation in the current study, greater value could be gained by probing awareness of infrequently used modes in a system that the pilots are familiar with to determine if any SA holes exist. Findings made by Sarter and Woods (1994) also support the proposition that pilot understanding of infrequently used modes was less than that of those commonly used. A future study examining the exact form of pilot FMS SA when operating with infrequently used modes would therefore be of value.

Another factor that has been discussed with regard to influencing SA scores is the workload participants experienced during testing. However, despite the potential influences of low workload, it is still likely that the results observed do approximate SA in a flight environment. The purpose of this study was to evaluate FMS SA, therefore any artificial manipulation of workload would distort the normal distribution of attention the pilot would apply. Ultimately this would not achieve the goal of this study. Greater accuracy could be gained by replicating the flight using a higher fidelity simulator, which would increase workload by requiring the pilot to perform all normal flight duties (such as fuel and systems management) during testing. In this way the results of this study could be tested further.

CHAPTER 6: CONCLUSIONS

Unfortunately due to the nature of the sample obtained generalising observations made during the present study to the wider pilot community is not possible. Therefore, all assertions must be viewed from this perspective, and conclusions are limited to statements about the group of pilots that participated in this study. In light of this limitation there are a few observations regarding the nature of pilot SA of FMS that are worthy of comment.

6.1 Situation Awareness

The results showed that this group of participants possessed a similar level of understanding for each of the three Levels of SA. Therefore, their SA, while not 100%, was complete in the sense that perception, comprehension and projection of the environment were all understood to a similar extent. In fact, a slight increase in correct responses was observed for each Level from Level 1 through to Level 3. While the significance of this increase is hard to determine, the good overall understanding is indicative of the experience, and as a result, the knowledge structures participants had probably acquired. Accordingly, these knowledge structures may have enabled these pilots to fill in gaps from preceding SA Levels, which may account for the increase in accuracy of SA observed at each level.

Focus of Situation Awareness

The strongest pattern observed in the data analysis was the tendency for pilots to answer questions regarding the FMS correctly more often than questions relating to primary flight data. The substantial tendency for the pilots surveyed to answer questions relating to the FMS correctly more often than primary data queries represented a noticeable shift in attention toward the FMS. This change in focus is more than would be expected to merely achieve adequate SA of the management system. However, despite the substantial shift in attention these pilots did not suffer from a total loss of primary flight data awareness. Instead it was observed that the accuracy of primary data knowledge was reduced. Generally, it appears that primary data was sampled less often, and as a consequence knowledge of this information lagged behind the actual situation.

While the focus of SA toward the FMS could be an effect of the participant's knowledge that the FMS was the subject of the study, or the visibility of the primary data, the difference is of a noticeable value. The magnitude of the tendency is such that after consideration is given to potential testing influences, there is more than likely a similar shift taking place in the real aircraft. As the complexity of information displayed by the FMS continues to increase, it is difficult to determine if this tendency for automation to dominate pilot attention is desirable or not. However, drawing the pilot's awareness away from primary data does reduce the possibility that he/she will detect an inappropriate flight manoeuvre caused by either an FMS failure, or an inappropriate system setting. As the density of commercial air traffic is projected to continue to increase in the foreseeable future, greater accuracy in handling of aircraft will be essential. If the automation introduced into the cockpit to achieve this accuracy also alters the pilot's SA so that their ability to monitor aircraft operation is reduced, the pilot's role as manager of the system could be compromised. In the absence of appropriate SA of primary data the pilot's ability to cross check achieved performance with intended performance will be diminished, and therefore the pilot's chances of detecting an error will be reduced. Consequently, their ability to manage the performance of the system will be adversely affected. To combat such an affect two approaches could be taken. One would require education of flight crews to maintain an awareness of primary flight information, and the second is to address system design. One design possibility discussed here was the development of FMS that operate in an agent like fashion, fostering a co-operative approach toward pilot management of automation. To achieve this the current operational objective could be communicated to the FMS. This would allow the automation to notify the crew if a disparity between the current objective and system set-up arises. However, careful consideration would have to be given to the method for communicating the current objective to the FMS to avoid creating another source of workload for the crew. If possible the system should be able to infer the objective from the current route programmed into the FMS, and seek confirmation from the crew if there is any ambiguity.

Schemata

From statements made by these pilots it would appear that their mental models could contain associations that incorporate precise explanations of system structure and functioning as well as default values. During testing participants displayed the use of a

rule of thumb formula to calculate unknown information. This implies that the mental model for this situation also held precise mathematical associations between elements, which the individual can apply to calculate expected values. Such a technique provides a valuable crosscheck of observed information, and establishes an expectation that can assist with anticipation of the situation. This technique comes at a cost however, as the data must be manipulated in working memory for the result to be calculated, causing an increase in cognitive workload.

6.2 Motivation

The motivational factors chosen in this study showed virtually no relationship with SA. Independently the measurements made displayed only random relationships with regard to SA. However, the very small sample size also means that it is not possible to discount the notion that motivation has an effect on SA, and further research into psychological factors affecting SA should still be considered. What could be drawn from these results is the possibility that the combined effects of different motivational factors might influence SA rather than a simple one to one association.

Assertiveness Erg

The results showed that amongst these pilots their assertiveness erg, which reflects an individual's drive for mastery and to perform well in competition, did not appear to relate to the level of SA achieved in any consistent manner.

Fear Erg

The results observed for the fear erg within this group of pilots also showed a very random effect. It would therefore appear that there was little relationship between the individual's desire to avoid life threatening or potentially harmful situations, and any tendency to search the environment to identify those situations. As a result, it appears that a heightened erg to identifying dangerous situations did not relate to a higher level of SA.

Career Sentiment

The results obtained in this study did not present a strong case for advocating that an increased interest in career progression caused these pilots to make a proactive effort to acquire more knowledge about their career that enhanced their SA.

Overall Motivational Effect

Even though in isolation the motivational results taken did not provide any evidence for a potential influence on SA, consideration of one case provides an interesting contrast. Within this sample the assertiveness and career motivation results for Respondent 2 were quite different to the remaining three candidates. When considering the greater flight experience possessed by this participant, and the moderate SA score achieved, it is possible that the combined effect of these motivational factors might have influenced this participant's SA. In this case, the possibility exists that high levels of assertiveness and low career drive does not lead to a conducive state for an individual to realise their maximum potential level of SA.

6.3 Experience

Surprisingly flight hours, which is the primary indicator used in the aviation profession to record experience, did not show any consistent variation with SA. This is contrary to the findings of previous research, and is almost certainly a consequence of the small sample size and the considerable experience that each participant had gained. Despite the fact that no direct relationships were evident, the sample did display some trends relating to experience that were of further interest.

Instructor Ratings

There was a tendency for individuals who had higher instructor rating qualifications to also achieve higher SA scores. Further testing should be performed to clarify this relationship, but as a tentative conclusion it would appear that, in this sample, airline instructors had better FMS SA abilities. Potentially, the causes for this tendency are two fold. In the sample of pilots obtained it would appear that firstly, deep learning of information that is needed to teach other pilots system operation might have resulted in better system understanding. As a result, the airline instructors had probably developed schemata and mental models capable of making more refined classifications and

discriminations. Secondly, it was proposed that the opportunity to observe other pilots operating the systems as part of the instructor role benefits the instructor's understanding of the system. A benefit to SA skills from the instructor's role could arise from observing a range of operating techniques, and the consequences of applying system modes in various situations. In addition to the variety of techniques, instructors will be able to observe how the system functions from a neutral standpoint, providing them with time to track system performance and refine their knowledge structures appropriately. However, the active crew would not be afforded the same opportunity to do so due to other workload demands. Exposure to this variety of operating techniques, and the possibility that the neutral observation role may provide the instructor with the capacity to incorporate new information into their mental models, could contribute to development of SA related abilities. This possibility needs to be evaluated more stringently with a larger sample, but implies that there could be a potential benefit from observing system operation in a way that enables an individual to refine their mental models of that system.

Ab-Initio Training Scheme

Because of the advantages to SA provided by sound knowledge structures the style of initial flight training was also evaluated. As discussed there was some support found in the data to suggest that a shorter training course was associated with better SA results. Support for this prospect was identified in the analysis of both the course length, and whether the programme was full time or casual. However, these results must be interpreted with care due to the markedly different ab-initio training received by one of the participants. When consideration is given to the dual training programme that Respondent 4 (who achieved the highest SA score) was exposed to, the effect of course length is drawn into question. If Respondent 4 is removed from the analysis the magnitude of the effect implied by the remaining participants is significantly reduced. Therefore, the initially very promising relationship observed might be misleading. Despite this limitation, the overall pattern displayed by all three ab-initio indicators was congruent. The implication that could be taken from this group of pilots is that ab-initio training may have an impact on SA abilities. However, the magnitude and direction of any potential effect cannot be determined from this sample. Therefore, future research designed to evaluate the impact of ab-initio training on SA ability could reveal information valuable to the flight training fraternity.

6.4 Level Of Automation

While not a focus of the present study, concern over the amount of time crew members spend heads down operating aircraft automation gave rise to discussion on the effects of LOA on SA. This was also partly supported by the tendency for participants to answer FMS questions correctly more often than queries relating to primary data. While not conclusive, this tendency does support the proposition that the pilot's attention is being dominated by the FMS. It is difficult to determine whether this tendency is a good or bad trend from the information gathered. However, with the increasing density of commercial air traffic adherence to flight procedures is also becoming increasingly critical throughout the entire flight envelop. Therefore, the tendency for FMS to dominate the pilot's SA represents a subject worthy of further investigation. To this end a suggested procedure to evaluate how pilot SA varies with LOA is proposed in the following section. The procedure suggested is intended to determine if increasing automation is in fact beneficial to pilot SA, assuming that no automation represents the control case. If the concerns over excessive heads down time in the cockpit are correct, it would be expected that SA scores would peak at an intermediate LOA. The results of such a study would provide a valuable indicator to pilot trainers and aircraft designers regarding the impact that cockpit automation has on pilot SA.

If the trend for the FMS to dominate the pilot's SA as found in this study holds true, a viable option to increase pilot SA of primary information could be to augment FMS information with primary data. In this way the automation could make use of the pilot's tendency to focus on information it provides, rather than forcing the pilot to spread their limited attention over a larger environment.

CHAPTER 7: RECOMENDATIONS

7.1 Promoting FMS Situation Awareness

Results from the SAGAT data suggest that the pilots who held airline instructor ratings achieved better SA scores. This points to a potential benefit these individuals gain by virtue of their instructor positions. It was hypothesised that this benefit arises from the need for the instructors to have a deeper understanding of the FMS to teach its operation, and also from a potential benefit afforded by the instructor's role as a neutral observer of FMS operating techniques. As a result they are presented with a greater range of opportunities to refine their mental models of system operation, enabling them to achieve higher levels of SA. However due to the limitations imposed by the sample gathered for this study, the significance of either of these possible causes cannot be determined. Therefore, it is recommended that further evaluation be undertaken to establish whether relevant flight instructor experience has a beneficial affect on an individual's SA ability.

7.2 Motivation

While the measures of motivation taken in this study did not identify any noteworthy associations, this should not rule out future studies testing the relationship between SA and operator psychological state.

7.3 The Impact of Ab-Initio Training on Situation Awareness

The discussion identified that the type of initial flight training received might have an influence on SA abilities. The strength of this affect, and the style of training that was of greatest benefit, could not be identified from these results. Therefore, further investigation of the relationship that might exist between ab-initio training and SA could provide valuable information to assist flight trainers design courses to maximise development of relevant SA knowledge structures.

7.4 Heads Down Trend and Level Of Automation

Concern over the disproportionate amount of time that crew members need to dedicate to operation of aircraft FMS was expressed as a particular concern by the pilots who

participated in this study. The trend observed in the SAGAT results for the FMS to dominate pilot SA partially supported this concern, and indicates an effect of LOA on SA. Further research in this area could be of significant value and it is recommended that the effect of FMS operating modes on pilot SA be investigated further.

To quantify the effect of LOA on pilot SA, a possible procedure follows that compares the SAGAT results of crews assigned to operate an aircraft using a fixed LOA. It is hypothesised that the highest LOA may not promote the highest levels of SA throughout all flight phases due to the time required to interact with the automation.

7.4.1 Evaluating Situation Awareness At Various Levels Of Automation

To evaluate whether SA is affected by LOA, some control must first be exercised over the LOA available. By instructing flight crews to fly a set flight procedure using a specific LOA, a series of SAGAT evaluations could determine what relationship, if any, exists between LOA and SA. Before any evaluations can occur, it is necessary to define:

- * The boundaries for the different LOAs to be used,
- * The SAGAT queries for each LOA, and
- * The flight procedure the pilots will fly.

Setting The Level Of Automation

Current commercial aircraft can be operated in three distinct LOA, these are:

- 1) Manual Control, in which the pilot plans the desired profile and flies the aircraft accordingly.
- 2) Batch Processing, in which the pilot plans the desired profile and instructs the autopilot to fly the aircraft accordingly.
- 3) Decision Support provided by FMC calculations, and control of the aircraft.

These three levels represent very distinct operational methods and are easily identified. They therefore provide a natural trichotomy to define the LOA utilised by the flight crews during SAGAT evaluations. Crews could then be randomly assigned to fly the same flight procedure using only one LOA. It is important that the entire flight, or as much of the flight as practical, is completed using only the assigned LOA. For instance,

if a crew is assigned to the Decision Support group, they should only use FMC programming to achieve the desired control over the flight. Similarly, if assigned to the Batch Processing group the crew should only use autopilot modes to fly the aircraft, and no reference to FMC flight guidance should be made. If this is done a good indication of SA at each LOA can be obtained allowing the results from each LOA group to be compared to determine how SA might be affected.

One further LOA group could be added to the evaluation, which could be considered the natural group. This group should be allowed to fly the procedure using any LOA they consider appropriate, reflecting how the system would be operated in the real environment. In this way comparisons between the natural group and the three restricted LOA groups might indicate if crews are using the automation effectively to enhance their SA.

Focus Of SAGAT Queries

In commercial aircraft FMS each automatic system represents a different layer of automation between the pilot and the aircraft. These layers can essentially be considered hierarchical in nature, with higher layers of automation having greater capabilities and, therefore, increasing the LOA. To operate at an LOA at the top of the tree the pilot would be required to monitor all of the elements relevant to the lower layers as well as the new system elements. For this reason all the queries administered to the Manual Control group could be administered to the Decision Support group, however, the reverse is not true. The Manual Control group will not have FMC or autopilot functions at their disposal, so have no need for an awareness of those elements. This imposes a limitation on the composition of SAGAT queries administered to each group.

To be able to compare SA scores across groups a common series of SAGAT queries will be needed for all groups. Analysing the demands of the lowest LOA group, in this case the Manual Control group, would identify these common queries. The subject matter of queries that are relevant to this group would also be relevant and available to all other LOA groups. However, the SAGAT database for each of the higher LOA groups needs to incorporate queries on the new automation elements introduced by the LOA assigned to that group. This is necessary to adhere to the global testing technique

inherent to the SAGAT procedure, which is essential to minimise the risk of directing the participants SA (Endsley, 1995a).

By developing SAGAT queries in a layered fashion such as this, any shift of attention from primary information to the automation, and the impact on SA as a whole can be detected. The Manual Control condition would provide a base line condition for attention to primary data, and SA under the highest pilot workload (Carmody & Gluckman, 1993). Any variation in SA observed in the higher LOA groups would then provide an indication of the degree to which increasing automation is beneficial to pilot SA.

The Flight Procedure

In order to enhance the validity of comparing SA scores from each LOA group, each group should be required to fly the same flight procedure. The procedures chosen should be sufficiently dynamic to force the crew to interact with the environment, and automation where applicable. A takeoff followed by a return to the departure airport would be a good example of such a flight, and incorporates both departure and arrival phases of flight where workload is high and objectives change rapidly.

A more extensive procedure would be to evaluate SA over an entire A to B flight, and break the overall SA score into scores for each phase of flight. This would allow SA scores for each phase of flight to be compared with the LOA and determine if there is any advantage to using a particular LOA during a specific phase of flight.

ABREVIATIONS

A/C	Aircraft
ATC	Air Traffic Control
CDI	Course Deviation Indicator
ETA	Estimated Time of Arrival
FBW	Fly By Wire
FMA	Flight Mode Annunciator
FMC	Flight Management Computer
FMS	Flight Management System
IRS	Inertial Reference System
LOA	Level of Automation
MAT	Motivation Analysis Test
NDM	Naturalistic Decision Making
ROC	Rate of Climb
ROD	Rate of Descent
RNZAF	Royal New Zealand Air Force
RPD	Recognition Primed Decision-Making
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
TOC	Top of Climb
TOD	Top of Descent
V ₁	Take-off decision speed
V _R	Rotation speed

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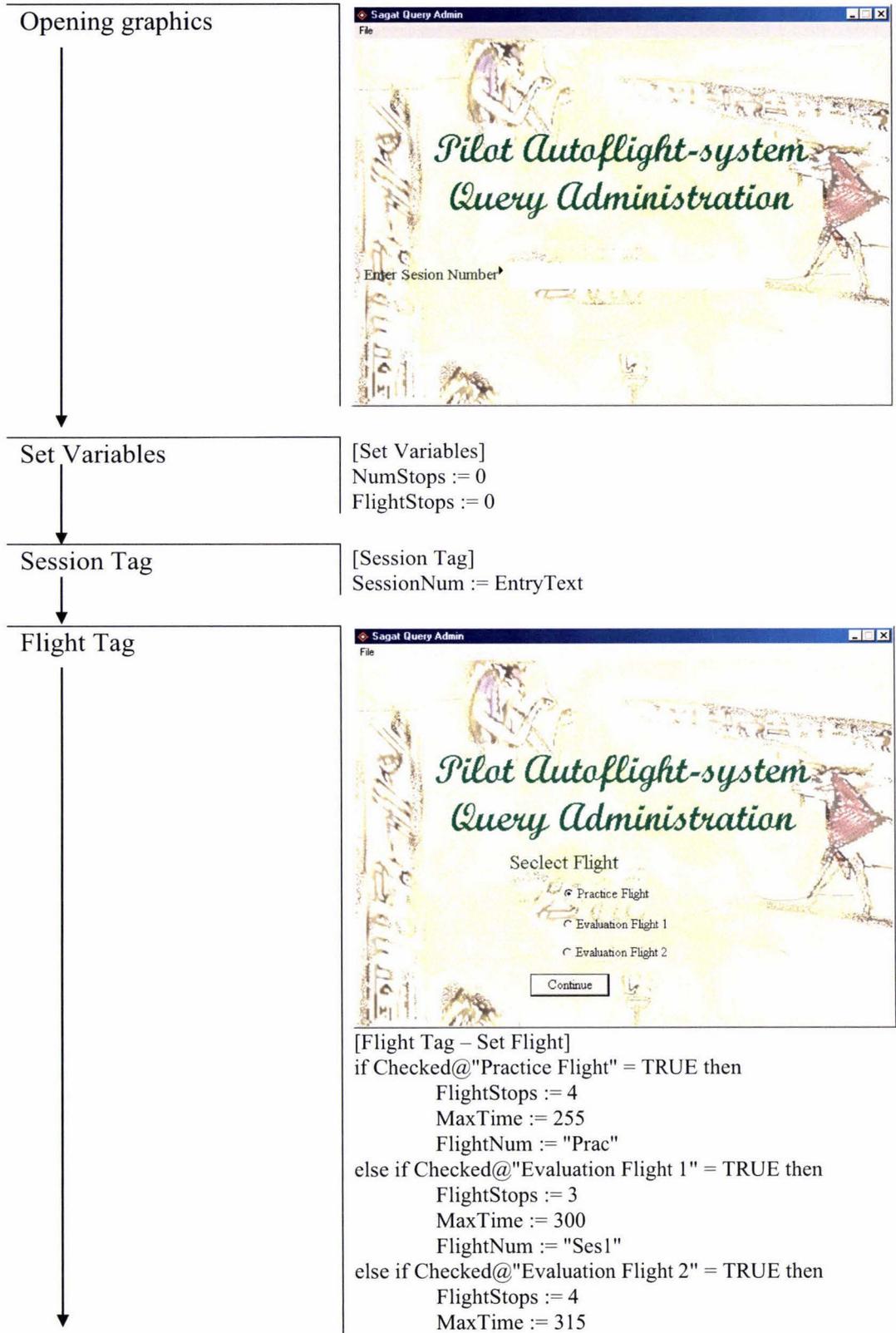
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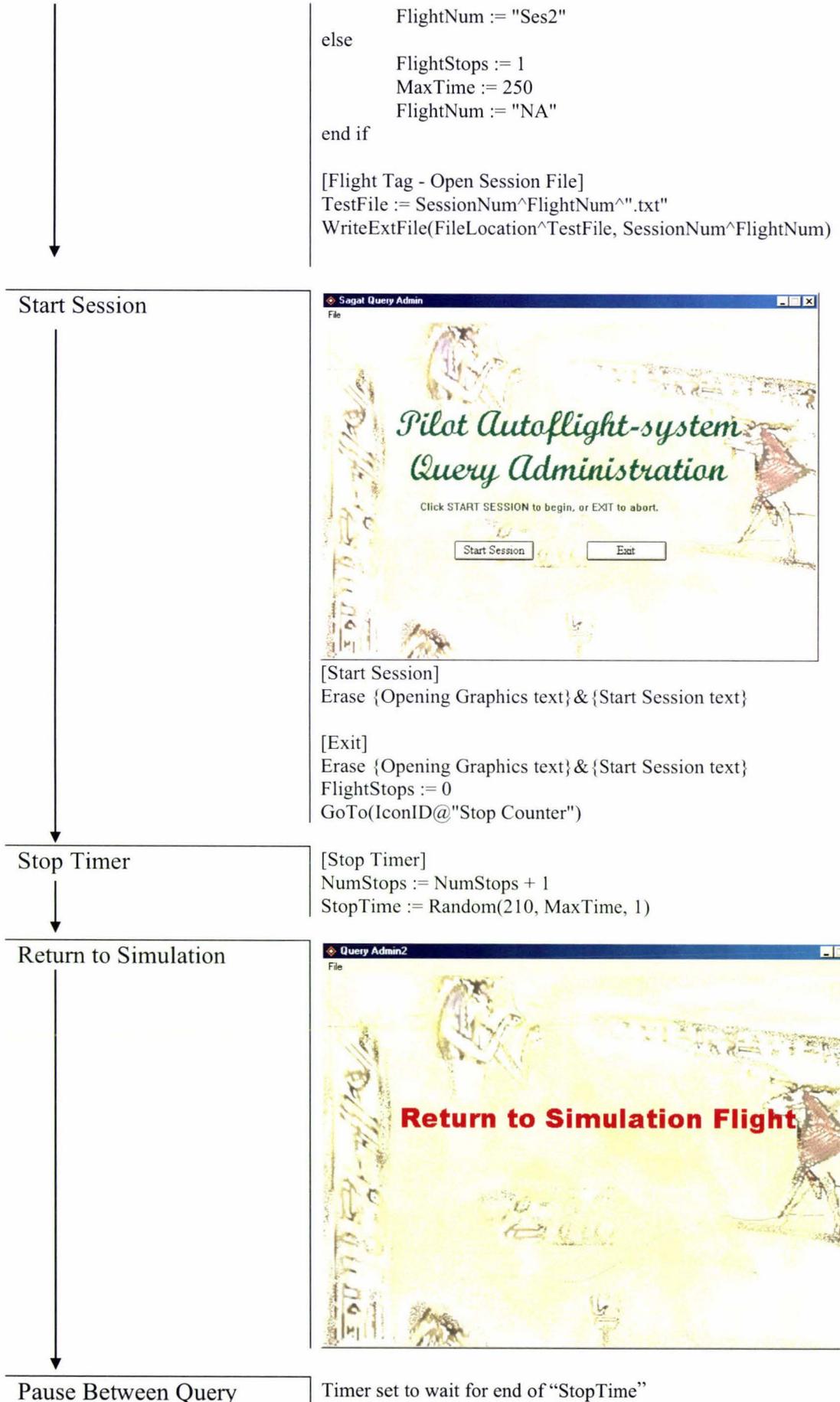
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APPENDIX 1: SAGAT Administration Programme Code

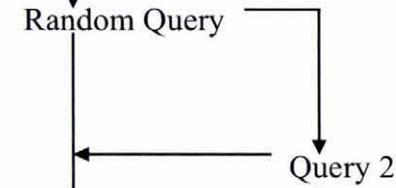
The following documentation describes the Authorware4 code used to administer SAGAT queries.





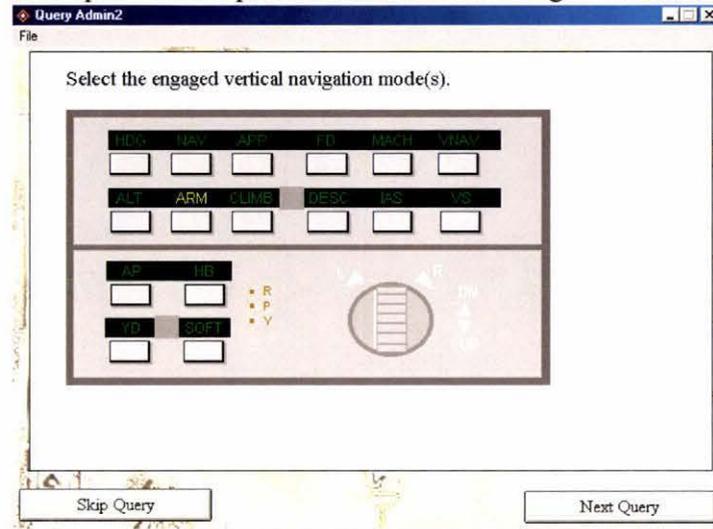
↓
 Erase Return to Simulation | Erase {Return to Simulation text}

Query Start Sound | Play Chime.wav



Query session set to randomly select each of the 27 SAGAT queries once, or until 120 seconds has elapsed, before ending.

Examples of the queries and associated logic follows:



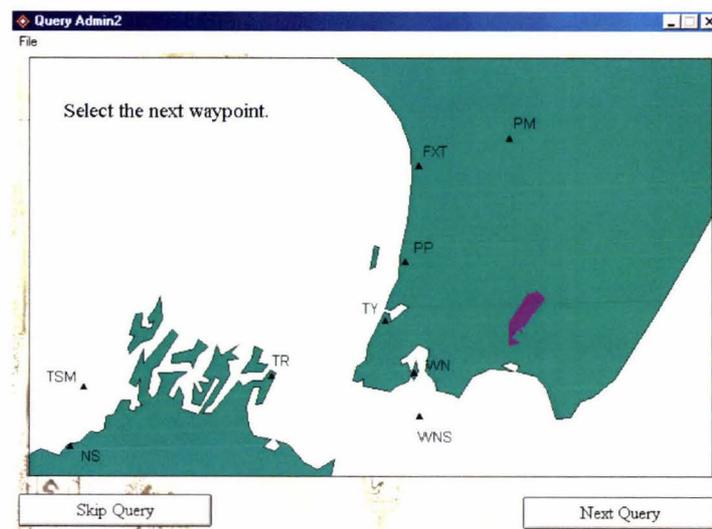
```

[Next Query]
--Reset variables
QueryResponse := ""
AddToFile := ""
--Determines which options have been selected.
if Checked@"HDG2" = TRUE then
    QueryResponse := QueryResponse^"Hdg,"
end if
if Checked@"NAV2" = TRUE then
    QueryResponse := QueryResponse^"Nav,"
end if
if Checked@"APP2" = TRUE then
    QueryResponse := QueryResponse^"App,"
end if
if Checked@"VNAV2" = TRUE then
    QueryResponse := QueryResponse^"VNav,"
end if
if Checked@"ALTHLD2" = TRUE then
    QueryResponse := QueryResponse^"Alt Hold,"
end if
if Checked@"ALTSEL2" = TRUE then
    QueryResponse := QueryResponse^"Alt Select,"
end if
if Checked@"CLIMB2" = TRUE then
    QueryResponse := QueryResponse^"Climb,"
end if
if Checked@"DESC2" = TRUE then
    QueryResponse := QueryResponse^"Descent,"
end if
if QueryResponse = "" then
    QueryResponse := QueryResponse^"Nothing Selected"
end if
  
```

```
--Adds query title to selected options
QueryTitle := "\rStopNumber"^NumStops^"\tQuery02:\t"
AddToFile := QueryTitle^QueryResponse
--Appends Query title and selected options to the Session file.
AppendExtFile(FileLocation^TestFile, AddToFile)
```

```
[Skip Query]
--Appends Query title and that the query was not answered.
QueryTitle := "\rStopNumber"^NumStops^"\tQuery02:\t"
AddToFile := QueryTitle^"Not Answered"
AppendExtFile(FileLocation^TestFile, AddToFile)
```

← Query 7



```
[Next Query]
--Reset variables
QueryResponse := ""
AddToFile := ""
--Determines which options have been selected.
if Checked@"NZPM" = TRUE then
    QueryResponse := QueryResponse^"NZPM,"
end if
if Checked@"FXT" = TRUE then
    QueryResponse := QueryResponse^"FXT,"
end if
if Checked@"NZPP" = TRUE then
    QueryResponse := QueryResponse^"NZPP,"
end if
if Checked@"TY" = TRUE then
    QueryResponse := QueryResponse^"TY NDB,"
end if
if Checked@"NZWN" = TRUE then
    QueryResponse := QueryResponse^"WN NDB,"
end if
if Checked@"WNS" = TRUE then
    QueryResponse := QueryResponse^"WNS,"
end if
if Checked@"TR" = TRUE then
    QueryResponse := QueryResponse^"TR VOR,"
end if
if Checked@"NZNS" = TRUE then
    QueryResponse := QueryResponse^"NZNS,"
end if
if Checked@"TSM" = TRUE then
    QueryResponse := QueryResponse^"TSM,"
```

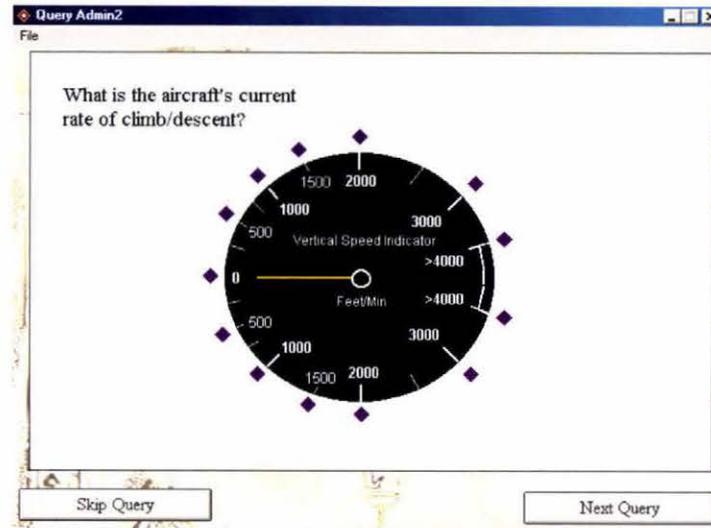
```

end if
if QueryResponse = "" then
    QueryResponse := QueryResponse^"Nothing Selected,"
end if
--Adds query title to selected options
QueryTitle := "\rStopNumber"^NumStops^"\tQuery07:\t"
AddToFile := QueryTitle^QueryResponse
--Appends Query title and selected options to the Session file.
AppendExtFile(FileLocation^TestFile, AddToFile)

[Skip Query]
--Appends Query title and that the query was not answered.
QueryTitle := "\rStopNumber"^NumStops^"\tQuery07:\t"
AddToFile := QueryTitle^"Not Answered"
AppendExtFile(FileLocation^TestFile, AddToFile)

```

← Query 11



```

[Next Query]
--Reset variables
QueryResponse := ""
AddToFile := ""
--Determines which options have been selected.
if Checked@"Zero" = TRUE then
    QueryResponse := QueryResponse^"Zero,"
end if
if Checked@"P500" = TRUE then
    QueryResponse := QueryResponse^"+500ft/min,"
end if
if Checked@"M500" = TRUE then
    QueryResponse := QueryResponse^-500ft/min,"
end if
if Checked@"P1000" = TRUE then
    QueryResponse := QueryResponse^"+1000ft/min,"
end if
if Checked@"M1000" = TRUE then
    QueryResponse := QueryResponse^-1000ft/min,"
end if
if Checked@"P1500" = TRUE then
    QueryResponse := QueryResponse^"+1500ft/min,"
end if
if Checked@"M1500" = TRUE then
    QueryResponse := QueryResponse^-1500ft/min,"
end if
if Checked@"P2000" = TRUE then

```

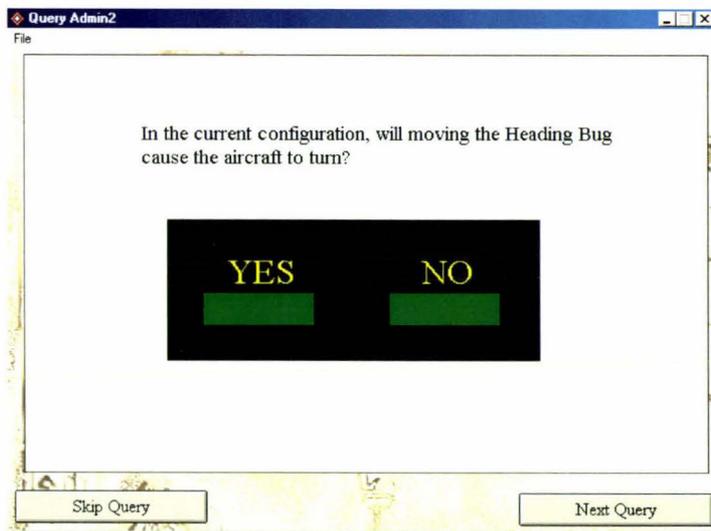
```

QueryResponse := QueryResponse^"+2000ft/min,"
end if
if Checked@"M2000" = TRUE then
    QueryResponse := QueryResponse^-2000ft/min,"
end if
if Checked@"P3000" = TRUE then
    QueryResponse := QueryResponse^"+3000ft/min,"
end if
if Checked@"M3000" = TRUE then
    QueryResponse := QueryResponse^-3000ft/min,"
end if
if Checked@"P4000" = TRUE then
    QueryResponse := QueryResponse^">+4000ft/min,"
end if
if Checked@"M4000" = TRUE then
    QueryResponse := QueryResponse^">-4000ft/min,"
end if
if QueryResponse = "" then
    QueryResponse := QueryResponse^"Nothing Selected,"
end if
--Adds query title to selected options
QueryTitle := "\rStopNumber"^NumStops^"\tQuery11:\t"
AddToFile := QueryTitle^QueryResponse
--Appends Query title and selected options to the Session file.
AppendExtFile(FileLocation^TestFile, AddToFile)

[Skip Query]
--Appends Query title and that the query was not answered.
QueryTitle := "\rStopNumber"^NumStops^"\tQuery11:\t"
AddToFile := QueryTitle^"Not Answered"
AppendExtFile(FileLocation^TestFile, AddToFile)

```

← Query 25



```

[Next Query]
--Reset variables
QueryResponse := ""
AddToFile := ""
--Determines which options have been selected.
if Checked@"Yes3" = TRUE then
    QueryResponse := QueryResponse^"True,"
end if
if Checked@"No3" = TRUE then
    QueryResponse := QueryResponse^"False,"
end if

```

```

if QueryResponse = "" then
    QueryResponse := QueryResponse^"Nothing Selected,"
end if
--Adds query title to selected options
QueryTitle := "\rStopNumber"^NumStops^"\tQuery25:\t"
AddToFile := QueryTitle^QueryResponse
--Appends Query title and selected options to the Session file.
AppendExtFile(FileLocation^TestFile, AddToFile)

[Skip Query]
--Appends Query title and that the query was not answered.
QueryTitle := "\rStopNumber"^NumStops^"\tQuery25:\t"
AddToFile := QueryTitle^"Not Answered"
AppendExtFile(FileLocation^TestFile, AddToFile)

```

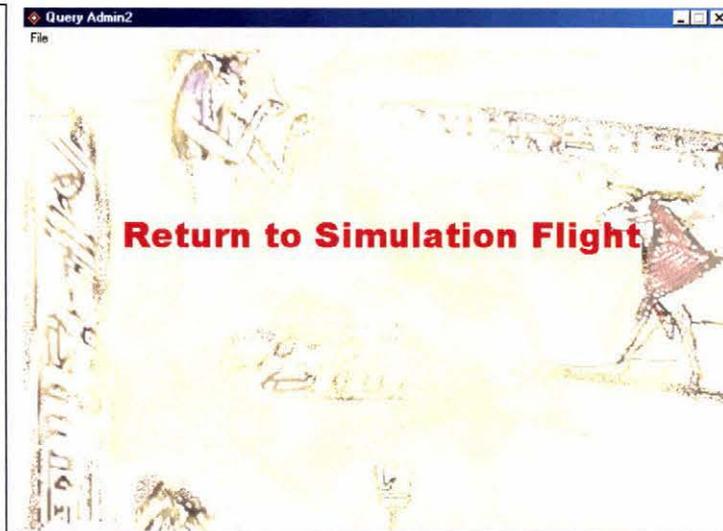
Stop Counter

```

[Stop Counter]
if NumStops < FlightStops then
    GoTo(IconID@"Stop Timer")
end if

```

End Title



APPENDIX 2: Motivational Analysis Test

MAT

This is not a test of intelligence or other abilities. It is to enable you to tell something about your thoughts and interest. It is to your advantage to answer as freely and frankly as you can.

There are four distinct subtests in this booklet and each begins with instructions and examples, which you will go through with the person giving the test. The researcher will tell you when to start and when to stop each test.

Your answers should be placed on the following sheets of this booklet.

USES (Subtest 1)

In this test you are asked what seems to you to be the better use to make of a given amount of time, money etc., under given circumstances. For example:

- I. If someone had all the money they needed, they'd use it better by:
 - Just enjoying themselves
 - Studying abroad.

Work quickly and place a check (X) in the box next to each case that seems to YOU the more attractive answer. Sometimes it might be hard to choose between the two answers, but always *choose one* (and *only one*). If you have a question please ask the researcher.

Uses Subtest

1. A person with time to read could use it better by:
 - Learning how to minimise the chance of developing melanoma.
 - Finding how to do still better in his/her job.

2. A valuable course of study would be one on:
 - Improving job related skills and techniques.
 - Health through relaxation.

3. If I could, I would spend more effort trying to:
 - Master undesirable impulses.
 - Employ people profitably.

4. An interesting subject to investigate would be:
 - Success in business.
 - The ideal sports role model.

5. Young people should devote time to:
 - Doing well in education courses.
 - Understanding themselves better.

6. One advantage of knowing your boss better is that:
 - You feel more secure in your job.
 - It improves chances of promotion.

7. If I could talk to one of these historical characters, I would prefer it to be:
 - John Dillinger, the notorious murderer.
 - Henry Ford, designer of automobiles.

8. I would prefer to learn from a subject matter expert more about the fundamentals of:
 - Job success.
 - A successful relationship.

9. A good use for \$100 would be to:
 - Save it in case of accident and/or illness.
 - Buy your parents something they need.

10. A Christmas bonus could better be spent on:
 - An emergency kit for a major earthquake.
 - Charity.

Uses Subtest

11. If I were a doctor (M.D.), I would prefer to:
 - Set up practice in a poor area lacking a doctor.
 - Spend my time trying to find a cure for cancer.

12. In a good magazine article, I would prefer to see explained:
 - What things make people fall in love.
 - What processes drive global warming.

13. More money should be spent on:
 - Developing more attractive public buildings.
 - Finding ways to reduce/reverse global warming.

14. A small cash present could better be spent:
 - Getting some new clothes.
 - Treating oneself to a really good meal with all the trimmings.

15. People join a local mental health movement to:
 - Learn more about the prevention of mental illness.
 - Work with their neighbours in a worthwhile activity.

16. An advantage of having a lot to do with people is that you:
 - Get a chance to show leadership qualities.
 - Learn mutual respect and trust.

17. A good magazine should have articles on:
 - Happiness in marriage.
 - Current fashions of dress.

18. It would be more interesting to read a pamphlet on:
 - Cutting edge interior decorating trends.
 - The prevention of mental disorder.

19. Being an army general could give a person:
 - A chance to “knock hell” out of his/her country’s enemies.
 - A sense of authority.

20. A job with shorter hours and more pay would allow one:
 - To enjoy more time with one’s partner.
 - To become a more influential person.

ESTIMATES (Subtest 2)

Instructions: Each item in this test has four possible answers. You are to circle the answer that you think best. For example:

I	The library is the best place to study.	A VERY TRUE	B TRUE	C FALSE	D VERY FALSE
---	---	-------------------	-----------	------------	--------------------

In an item like this, *VERY TRUE* means that in your experience there are very few exceptions and that you strongly agree;
TRUE means that it tends to be true more often than it is false and that you agree moderately;
FALSE means that you tend to disagree and that in your experience it is more often untrue;
VERY FALSE means that in your experience it is almost always untrue and that you disagree strongly.

In other questions you are asked to make your *best* estimate of a truly correct answer. For example:

II	The next major earthquake is likely to occur in ??? years	A 1	B 5	C 20	D Never
----	---	--------	--------	---------	------------

No one knows the answer to a question like this, but everyone can make an estimate (and some estimates will be more accurate than others). Indicate your judgment by circling the appropriate answer on the following sheet. If the estimate you would make is not among those listed, mark the answer that is closest.

The questions which follow either ask for a true or false choice like the first above or for a quantity like the last.

Estimates Subtest

	A	B	C	D
1 All careers are becoming so crowded that one can no longer expect to “reach the top.”	Very False	False	True	Very True
2 If greenhouse gas emissions are not significantly reduced irreparable damage will be done in	4 years	8 years	12 years	20 years
3 What percentage of people feel that a person’s status is properly shown by their appearance and that “clothes make the man or woman”?	80%	50%	20%	0%
4 In most careers it isn’t how a person looks, but how he or she thinks that counts	Very True	True	False	Very False
5 The expenditure of cities to protect their citizens from environmental damage has increased in ten years by	20%	50%	100%	200%
6 On average, hand-tailored clothes, which look so much better, cost only ? percent more than pre-cut clothes?	40%	25%	15%	8%
7 In order to impress a wo/man, a wo/man sometimes takes valuable time from her/his career	Very False	False	True	Very True
8 Modern life has increased heart disease above that in our parent’s time by	0%	7%	15%	30%
9 High social status is more of a spiritual quality, not chiefly determined by money or acknowledged success	Very True	True	False	Very False
10 Union and professional association dues are more than you’d expect from the amount they help a person	Very True	True	False	Very False
11 Even when a rabies outbreak is over, it is desirable to keep a dog muzzled for another	6 mth	3 mth	1 mth	1 wk
12 Which of the following income brackets is the minimum that any informed person would call “upper middle” class?		(a)	\$75,000	
		(b)	\$65,000	
		(c)	\$55,000	
		(d)	\$45,000	

PAIRED WORDS (Subtest 3)

In this test you will find groups of three words like this:

- | | |
|------------------------------------|------------------------------------|
| <input type="checkbox"/> Birthday | <input type="checkbox"/> Policeman |
| 1) PARTY | 2) TRAFFIC |
| <input type="checkbox"/> Political | <input type="checkbox"/> Accident |

You are to read first the “key” word in CAPITAL letters which has a number by it. Then decide which of the two “association” words, above and below, that the key word makes you think of. For example, after PARTY the word that springs to your mind might be “birthday” or “political”.

Once you start this Subtest check (X) the most natural word that comes to you for each “key” word. Do not skip any items but move along fast, choosing the first of the two association words that comes to your mind. If you have a question please ask the researcher.

Paired Words Subtest

- | | | |
|---|--|---|
| <input type="checkbox"/> Earthquake safe
1) HOME
<input type="checkbox"/> Of learning | <input type="checkbox"/> Dinner's Club
2) MEMBER
<input type="checkbox"/> Labour Union | <input type="checkbox"/> Manner
3) SKILLED
<input type="checkbox"/> Job |
| <input type="checkbox"/> Employment
4) SECURE
<input type="checkbox"/> Reputation | <input type="checkbox"/> Command
5) SELF
<input type="checkbox"/> Career | <input type="checkbox"/> Home
6) IMPORTANT
<input type="checkbox"/> Virtue |
| <input type="checkbox"/> Operational
7) TECHNIQUES
<input type="checkbox"/> Romantic | <input type="checkbox"/> Position
8) PERMANENT
<input type="checkbox"/> Wave | <input type="checkbox"/> Parents
9) OBEY
<input type="checkbox"/> Traffic laws |
| <input type="checkbox"/> Club
10) COUNTRY
<input type="checkbox"/> Cottage | <input type="checkbox"/> Car airbags
11) PROTECTION
<input type="checkbox"/> Civil defence | <input type="checkbox"/> Fashionable
12) SMART
<input type="checkbox"/> Faultless |
| <input type="checkbox"/> Donor
13) BLOOD
<input type="checkbox"/> Transfusion | <input type="checkbox"/> Temptation
14) AVOID
<input type="checkbox"/> Losing | <input type="checkbox"/> Germs
15) DESTROY
<input type="checkbox"/> Enemy |
| <input type="checkbox"/> Chair
16) ELECTRIC
<input type="checkbox"/> Personality | <input type="checkbox"/> Romantic
17) FALLOUT
<input type="checkbox"/> Radioactive | <input type="checkbox"/> Fashion
18) GOOD
<input type="checkbox"/> Partner |

INFORMATION (Subtest 4)

Instructions: This test is designed to measure the amount of information you have about various areas of knowledge. There are always four answers from which you are to choose *one*. For example:

- I. How many days are there in February in a leap year?
- a. 28.
 - b. 29.
 - c. 30.
 - d. 31.

Please make a choice on all questions by circling your answer. In every case there is a best answer or one that is more true than the others. Even if you don't know the correct answer, *make a guess*. Work quickly. If there are any questions, please ask the researcher.

Information Subtest

1. The share of child's support that the parent must contribute in order to claim that child on income tax as a dependent is more than:
 - a. Three-quarters
 - b. Two-thirds
 - c. One-half
 - d. One-third

2. When did the Bataan death march occur?
 - a. 1944
 - b. 1943
 - c. 1942
 - d. 1941

3. Which of the following materials characteristically holds a press, but may shrink when dry-cleaned?
 - a. Wool
 - b. Nylon
 - c. Cotton
 - d. Dacron

4. Which of the following is the least reliable sign of a person's success in their career or job?
 - a. Their position of seniority
 - b. Their rate of promotion
 - c. Their reputation in the trade or profession
 - d. How much a year he/she earns

5. The best place to be in the event of a nuclear bomb attack is:
 - a. On the first floor of a brick building
 - b. Behind a concrete block wall
 - c. In a factory building
 - d. In a four-foot slit trench

6. What is the process for freeing a person illegally held in jail?
 - a. Subpoena
 - b. Habeas corpus
 - c. Tor de defence
 - d. Injunction

Information Subtest

7. Which type of school is least concerned with worker's learning the particular skills of jobs?
 - a. Universities
 - b. Correspondence schools
 - c. Vocational schools
 - d. Secondary schools

8. For safety purposes, which is the best arrangement in moving vehicles?
 - a. The seats should have safety belts
 - b. The seats should face away from the direction of motion
 - c. The seats should not be near windows
 - d. The seats should not be near doors

9. Which of the following types of behaviour would be most approved by parents?
 - a. Marrying a person they admire
 - b. Helping them financially in old age
 - c. Seeking their guidance
 - d. Graduating from college

10. Which of these would most likely cause you to lose your reputation in the community?
 - a. Going bankrupt
 - b. Conviction for drunken driving
 - c. Conviction for income tax evasion
 - d. Being arrested in a place not licensed for drinking

11. Which of the following diets reduces the possibility of heart disease?
 - a. Low-fat diets
 - b. Alcohol-free diets
 - c. Low-protein meals
 - d. Small but frequent meals

12. Which of these forms of business requires a charter from the government?
 - a. Partnership
 - b. Proprietorship
 - c. Corporation
 - d. Company

APPENDIX 3: Pilot Flight Experience Form

The following information is needed for analysis of the test results.

Age: _____	Gender: Female / Male	
Experience		
Total flight time (hrs): _____ FMS aircraft flight hours: _____		
I last flew an FMS equipped aircraft _____ yr / mth ago		
Licence held:		
CPL <input type="checkbox"/>	ATPL <input type="checkbox"/>	
IRT <input type="checkbox"/>		
Other: _____		
Instructor Rating(s):		
A Cat <input type="checkbox"/>	B Cat <input type="checkbox"/>	
C Cat <input type="checkbox"/>		
Simulator Instructor <input type="checkbox"/>	Training Captain <input type="checkbox"/>	
Flight Instructor <input type="checkbox"/>		
Other: _____		
Aircraft Rating(s) Held:		
B747 Classic <input type="checkbox"/>	B737 – 200 <input type="checkbox"/>	ATR 72 <input type="checkbox"/>
B747 – 400 <input type="checkbox"/>	B737 glass <input type="checkbox"/>	Dash 8 <input type="checkbox"/>
B767 <input type="checkbox"/>	BAe 146 <input type="checkbox"/>	EMB 110 <input type="checkbox"/>
		SAAB 340 <input type="checkbox"/>
		Metroliner III <input type="checkbox"/>
Other: _____		
Initial Training		
My ab-initio training was performed by:		The training schedule was:
Aero Club <input type="checkbox"/>	Full time <input type="checkbox"/>	
Flight School <input type="checkbox"/>	Casual <input type="checkbox"/>	
University Course <input type="checkbox"/>		
Air Force <input type="checkbox"/>		
Other: _____		
The training took _____ yr / mth to complete.		