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Pathological Behaviours in Pilots During Unexpected Critical Events: The Effects of Startle, Freeze and Denial on Situation Outcome

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Abstract

Over the last 40 years significant advances in aviation technology have contributed strongly to improvements in aviation safety. Recent figures suggest that fourth generation aircraft are now achieving fatal accident rates in the order of 10^{-7} and ongoing work continues to improve this rate. Significant improvements in engine and systems reliability, coupled with safety technologies such as Enhanced Ground Proximity Warning (EGPWS), Airborne Collision Avoidance Systems (ACAS), Global Positioning System (GPS), and Vertical Situation Displays (VSD) have contributed to reductions in accident rates. Additionally, initiatives such as RNAV and RNP (AR) approaches continue to improve non-precision approach accuracy and safety while air traffic control improvements continue to accommodate this increased safety as aircraft traffic continues to grow strongly.

Nevertheless, the reliability engendered by all these incremental improvements to safety has a downside. While pilots in the earlier years of airline transport had a healthy expectation for engine and systems failures, the modern airline pilot does not necessarily share this. Indeed, the modern airline aircraft is so reliable, and failures are so rare, that pilots are now unwittingly conditioned into an expectation of unwavering reliability. This unintentional complacency means that attention to emergency procedures and an expectation for dealing with real malfunctions is not as well honed as it perhaps once was.

The result of this conditioned expectation of normalcy is that when unexpected critical events occur, pilots are often genuinely surprised and don’t have readily accessible mental action plans on how to deal with them, unlike their predecessors who experienced emergencies on a regular basis. Over the last few years in particular, these “surprise” critical events have created situations where pilots have become startled or suffered the effects of acute stress, and as a result have acted inappropriately, ineffectively, or, in some cases, taken no action at all.

Startle is a ubiquitous human reflex, which is also common to most animals. Where a real threat persists however, startle can transition from a simple reflex action into a full stress response. This response, commonly known as the “fear-potentiated startle”, involves the arousal of the sympathetic nervous system, with considerable physiological changes occurring as a result. This response to a strong startle has been shown to cause significant impairment to both cognitive and psychomotor performance for some time afterwards, and in the context of a critical aviation

event could cause reduced situational awareness, decision-making and handling capabilities, with a potential impact on flight safety.

Similarly the onset of acute stress as a critical event unfolds has been shown to cause pathological behaviours in pilots. Behavioural inaction or freezing has occurred where pilots have suddenly become overwhelmed by stress to the point where they become unable to process sufficient information to act. Acute stress has also been shown to enact coping and defence mechanisms such as denial. These processes, which are not clearly delineated in the literature, appear to be both a strategic and a tactical means of stress avoidance, which may not be a conscious effort.

In examining these pathological behaviours, aircraft accident and incident analyses were conducted from two sources: accident and incident reports from recent history; and personal accounts from pilots who have experienced critical events. These case studies were analysed for iterations of startle, freeze and denial, with a substantial number of those examined revealing these pathological behaviours. Additionally, attempts were made to quantify the effects of startle using a B737 Flight Simulator. Eighteen volunteers were exposed to a startling stimulus at a critical stage of flight, measuring any reactionary delay and other qualitative reactions. Approximately one third of participants (n=7) showed pathological reactions to the startling stimulus.

Results from the case study analysis and the startle experiments suggested that the pathological behaviours of startle, freeze and denial have the potential to impact negatively on situation outcome, particularly during unexpected critical events.

Further research on these phenomena and training interventions to help better prepare pilots for unexpected critical events is required.

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signed: Date: 9 April 2013

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Secondly, I would like to thank my two supervisors, Associate Professors Paul Bates and Patrick Murray for their hard work and sage advice. Particular thanks go to Pat, who, as one of the aviation industry's most astute analysts, provided invaluable insight and unwavering support, and I thank him sincerely. Paul's worldly experience in the aviation and academic fields was especially helpful and proved invaluable in the final stages of constructing this thesis. Both Paul and Pat provided some wonderful guidance and motivation and without this, this study would never have come to fruition.

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List of Abbreviations

AAIB	-	Aircraft Accident Investigation Board
AAPID	-	Portuguese Accident Investigation Board
AMSL	-	Above Mean Sea Level
ACAS	-	Airborne Collision Avoidance System
ACTH	-	Adrenocorticotropic Hormone
ADR	-	Air Data Reference
ADS	-	Aeronautical Display System
AFM	-	Aircraft (or Airplane) Flight Manual
AGL	-	Above Ground Level
AMSL	-	Above Mean Sea Level
ANS	-	Autonomic Nervous System
AOA	-	Angle of Attack
ASI	-	Airspeed Indicator
ASRS	-	Aviation Safety Reporting System
ATC	-	Air Traffic Control
ATSB	-	Australian Transportation Safety Board
AVP	-	Arginine Vasopressin
B737NG	-	Boeing 737 New Generation
BEA	-	Bureau d'Enquêtes et d'Analyses
CAST	-	Commercial Aviation Safety Team
CAPT	-	Captain
CE	-	Central Nucleus (of the Amygdala)
CENIPA	-	Aeronautical Accident Investigation and Prevention Center
CFIT	-	Controlled Flight Into Terrain
CFR	-	Crash, Fire and Rescue
C&T	-	Check and Training
CNS	-	Central Nervous System
CPDLC	-	Controller Pilot Data Link Communication
CRH	-	Corticotropic Releasing Hormone
CRM	-	Crew Resource Management
CS	-	Conditioned Stimulus
CVR	-	Cockpit Voice Recorder
DA	-	Decision Altitude
DFDR	-	Digital Flight Data Recorder
DME	-	Distance Measuring Equipment

List of Abbreviations (continued)

ECAM	-	Electronic Centralised Alerting Module
EEG	-	Electroencephelograph
EFATO	-	Engine Failure After Takeoff
EGPWS	-	Enhanced Ground Proximity Warning System
EMAS	-	Engineered Materials Arrestor System
FANS	-	Future Air Navigation System
FBS	-	Fixed Base Flight Simulator
FD	-	Flight Director
FDR	-	Flight Data Recorder
FFS	-	Full Flight Simulator
FL	-	Flight Level
FMC	-	Flight Management Computer
FMS	-	Flight Management System
FO	-	First Officer
GPS	-	Global Positioning System
GPWS	-	Ground Proximity Warning System
HDG	-	Heading
HPA Axis	-	Hypothalamic-Pituitary-Adrenocortical Axis
HUD	-	Head Up Display
IAC	-	Interstate Aviation Commission
ICAO	-	International Civil Aviation Organisation
ILS	-	Instrument Landing System
IMC	-	Instrument Meteorological Conditions
ISIS	-	Integrated Standby Instrument System
KIAS	-	Knots Indicated Airspeed
LA	-	Lateral Nucleus (of the Amygdala)
LH	-	Lateral Hypothalamus
LNAV	-	Lateral Navigation
LOC-I	-	Loss of Control Inflight
LTM	-	Long Term Memory
MDA	-	Minimum Descent Altitude
MEL	-	Minimum Equipment List
MSA	-	Minimum Safe Altitude
NAV	-	Navigation Mode
NM	-	Nautical Miles

List of Abbreviations (continued)

NTSB	-	National Transportation Safety Board
PA	-	Passenger Address (or Announcement)
PAG	-	Pariacqueductal Central Grey
PBD	-	Place – Bearing – Distance
PBN	-	Performance Based Navigation
P-E	-	Person-Environment
PF	-	Pilot Flying
PFD	-	Primary Flight Display
PIA	-	Pakistan International Airlines
PM	-	Pilot Monitoring
PNF	-	Pilot Not Flying
PNS	-	Peripheral Nervous System
PSNS	-	Parasympathetic Nervous System
PTSD	-	Post Traumatic Stress Disorder
PVN	-	Paraventricular Nucleus
QRH	-	Quick Reference Handbook
RESA	-	Runway End Safety Area
RNP (AR)	-	Required Navigation Performance (Authorisation Required)
RPC	-	Reticulus Pontis Caudalis
RPK	-	Revenue Passenger Kilometre
RPM	-	Revolutions Per Minute
SCR	-	Skin Conductance Resistance
SEERC	-	South-East European Research Centre
SMGCS	-	Surface Movement Guidance Control System
SNS	-	Sympathetic Nervous System
SOP	-	Standard Operating Procedure
STM	-	Short Term Memory
STSS	-	Short Term Sensory Stores
TAIC	-	Transport Accident Investigation Board
TCAS	-	Traffic Collision Avoidance System
THS	-	Trimmable Horizontal Stabiliser
TOGA	-	Take Off and Go Around
TSB	-	Transportation Safety Board
UAS	-	Undesired Aircraft State

List of Abbreviations (continued)

US	-	Unconditioned Stimulus
V1	-	Go/No-Go Decision Speed on Takeoff
Vmo	-	Maximum Operating Airspeed
VOR	-	Very High Frequency Omni-directional Range
VS	-	Vertical Speed
VSD	-	Vertical Situation Display
WM	-	Working Memory

Declaration

Parts of this thesis have been presented at conferences or published in journals.

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Contents

CHAPTER 1 INTRODUCTION

1.1 Introduction

Since the commencement of airline jet operations (approximately 60 years ago), aircraft traffic has increased significantly, while aircraft safety has also improved markedly (Boeing, 2012a; ICAO, 2011, 2012a). In 1960 passenger aircraft flew 1.1 billion revenue passenger kilometres (rpk's) (ICAO, 1960), while by 2011 rpk's had risen to 5.3 trillion (ICAO, 2012a), an average growth rate of almost 9% pa (Transport & Environment, 2010). Furthermore, traffic growth is forecast to continue growing at an average rate of 4.8% per year through to the year 2036 (ICAO, 2010).

During this period airline safety has shown significant positive change, with a 100-fold improvement in the 50 years from 1945-1995 (ICAO, 2006). Even since 1995 the rate of improvement in aviation safety has continued, with accidents involving passenger fatalities in scheduled air transport operations (excluding accidents caused by acts of unlawful interference) dropping from 0.12 per 100,000 flights in 1995 to 0.04 in 2004, a reduction of 66% (ICAO, 2006). Over this ten-year period fatal accidents in scheduled airline operations decreased from 31 to 12 and by 2004 the number of passengers fatally injured was just 208 worldwide (ICAO, 2006). Beyond this period airline safety has further improved with an average of less than eight fatal airline accidents per year in the 10 years to 2011 (Boeing, 2012a). Indeed the probability of being in a fatal accident in a fourth generation airline jet aircraft is now in the order of 10^{-7} (Flight Safety Foundation, 2012).

To achieve this impressive safety rate, holistic improvements have been made, and continue to be made, in aircraft technology, in the aviation system itself, and in training for flight crew and others. These multi-faceted improvements have collectively reduced aircraft accident rates and will need to continue doing so as traffic density continues to grow (ACI, nd).

In terms of technological improvements, some of the most important initiatives have been in engine and system reliability (Ballal & Zelina, 2003; Boeing, 2009, 2013; Owen, 2001; Sabbatini, 2008). As an indicator of how much engine reliability has improved safety, from 1946 to 1958 U.S. air carriers averaged 4.5 major accidents and 50 fatalities per year from engine-related accidents, while in contrast, airline jet operators had just two engine-related fatal accidents between 1988 and 2007 (Sabbatini, 2008).

The early rules governing operations of aircraft were based on the reliability of piston engines in use at that time. In 1953 ICAO adopted a standard of 90 minutes diversion time, which limited all twin-engined and three-engined aircraft to routes which were never more than 90 minutes at one-engine-inoperative cruising speed from an adequate airport (Simpson & Aurotas, 1987). Despite this ICAO ruling, the US initially used 60 minutes (Simpson & Ausrotas, 1987) but this was relaxed for three-engined aircraft in 1964, and further relaxed to 120 minutes diversion time for twin-engined aircraft in 1985 (Simpson & Ausrotas, 1987). Indeed, the entry into service in the 1980s of the Boeing 767 and Airbus A300 twin engine aircraft signalled a major improvement in aircraft reliability and safety enhancements (Simpson & Ausrotas, 1987; Scholz, 1999). The level of sophistication, redundancy and reliability of aircraft engines and systems allowed operators to travel further in twin-engine aircraft and farther from suitable airports than had ever been possible previously (Simpson & Ausrotas, 1987). In fact, as reliability continues to improve, Boeing is currently working on certification to its 777 aircraft which would allow it to operate up to 330 minutes from a suitable airport (Boeing, 2013b) and there have been proposals for 350 minutes diversion time for Airbus' new A350 aircraft (Kaminski-Morrow, 2008).

Other technological improvements have come through the development of systems including Ground Proximity Warning Systems (GPWS) and its later improvement, Enhanced GPWS (Honeywell, 2004), windshear detection and alerting systems (Honeywell, 2004), the development and ubiquitous use of Airborne Collision Avoidance Systems (ACAS) (Harman, 1989; Kochenderfer, Holland & Chryssanthacopoulos, 2012; Law, 1999), Vertical Situation Displays (VSD) (Boeing, 2009), through extensive use of highly accurate navigation systems such as the Global Positioning System (GPS) (European Commission, 2011; FAA, 2012; Lee, 2005), head-up displays (HUDs) (Boeing, 2009), and using such other flight deck enhancements as improved flight information displays and electronic checklists (Boeing, 2009).

In addition to these technological advances, significant improvements have been made in the aviation system itself. Important initiatives include Future Air Navigation Systems (FANS-1) (Diez, 2013; Honeywell, nd), Controller Pilot Data Link Communication (CPDLC) (Honeywell, 2012), Automatic Dependent Surveillance (ADS) (EUROCONTROL, 1999; FAA, 2011a), Surface Movement Guidance and Control Systems (SMGCS) (FAA,2011b), Runway End Safety Areas/Engineered Material Arresting Systems (RESA/EMAS) (ICAO, 2012b), Next Generation Air Transportation System (NextGen) (ACI, nd), and Performance Based Navigation (PBN) (ICAO, 2009).

As well as technological advances and improvements in the broader aviation system, the training of flight crew and other operationally critical personnel, particularly in the area of human factors, crew resource management and non-technical skills, have made the human element in flight operations better equipped to deal with operations in a complex, high-risk industry (Fisher, Phillips, & Mather, 2000; Helmreich, Merritt & Wilhelm, 1999; Salas, Burke, Bowers & Wilson, 2001; Salas, Wilson, Burke & Wightman, 2006). Despite these initiatives however, airline accident statistics have consistently implicated pilots as strongly contributory to outcome (BASI, 1996; O'Hare, Wiggins, Batt & Morrison, 1994; Shappell & Wiegman, 2004; Wiegman & Shappell, 2001; Yacavone, 1996), and while actual figures vary slightly, human failings have been shown by accident data to be causal in 60-80% of all aircraft accidents (BASI, 1996; Shappell & Wiegman, 1996; Wiegman & Shappell, 2001).

Prior to the 1980s, "pilot error" was commonly cited as the cause of aircraft accidents, with accidents such as British European Airways Flight 708, United Airlines Flight 839, the KLM Flight 4805/Pan Am Flight 1736 Collision, Eastern Airlines Flight 401, and American Airlines Flight 383 (CAB, 1966; Flight Safety Foundation, nd; Ministerio de Transportes Comunicaciones, 1978; NTSB, 1967), typical of reports in which pilot error was stated as a principal cause.

Of these "pilot error" accidents, the most common cause prior to 1980 was "controlled flight into terrain" (CFIT), but the progressive and widespread introduction of GPWS/EGPWS from the 1970s onwards (COSCAP, 2008) had significant positive effects on preventing CFIT accidents (Honeywell, 2004). Whereas the CFIT accident rate in 1974 (pre-GPWS) was one per 800,000 departures, the CFIT accident rate was just one per 91 million departures by 2003 (Honeywell, 2004).

While the reduction in CFIT accidents over the last 35 years has significantly improved the incidence of aircraft accidents, what it has done is highlighted another significant cause. "Loss of Control Inflight" (LOC-I) accidents have, over recent years, overtaken CFIT as the most common cause of aircraft accidents (Boeing, 2012a; NASA, 2010). Indeed, data provided by the CAST/ICAO Common Taxonomy Team shows that in the ten years from 2002–2011, LOC-I accidents accounted for 1573 fatalities, whereas CFIT accounted for just 1078 fatalities (Boeing, 2012a).

Considerable work has recently been carried out to identify the causes of LOC-I and into developing interventions for reducing its incidence (e.g., Holloway & Johnson, 2008; NASA, 2010). One such study, by the NASA-Dryden research centre (NASA, 2010) identified several contributory factors to LOC-I. These were grouped into three major categories:

- Human-induced loss of control;
- Externally-induced loss of control; and
- Systems-induced loss of control.

While initiatives are under way amongst regulators, flight safety agencies and manufacturers to provide preventions for future iterations of LOC-I, the one element which will continue to provide challenges is the human element. As long as humans continue to make random human errors, are distracted by other things, suffer lapses in situational awareness, are susceptible to fatigue and stress, and continue to make poor decisions or exercise poor judgement, then unless training interventions and technological advances can be made to better prevent or to assist with recovery from these failings, Human induced loss of control will continue to be a problem.

Over the last few years in particular, there have been some LOC-I and CFIT accidents where the Pilots have been implicated as directly causal in fatal accidents, when they appeared to act either inappropriately, or at least ineffectively, when confronted with an unexpected critical situation. Some examples of these accidents are given in the following paragraphs.

In 2009 a Q400 operated by Colgan Airlines on behalf of Continental Express was on approach to Buffalo, New York, at night. The captain, who was not overly experienced, mismanaged configuring the aircraft for the approach, and allowed the airspeed to rapidly decay in level flight to the point where the stall warning stick shaker suddenly activated. It appears that both the captain and his first officer received a strong startle, and temporarily confused by the physiological and cognitive changes induced by this startle, made some very inappropriate control inputs which caused the aircraft to enter a fully developed stall, from which they failed to recover. Following the startle the captain pulled up sharply and the first officer retracted the flaps, both actions exacerbating the stall condition. The inappropriateness of both of these actions, which goes against all previous training, is not atypical of mishandling following startle (NTSB, 2010).

In another incident, while on an approach to land, a very experienced captain suddenly froze on the controls as the aircraft entered cloud during an Instrument Landing System (ILS) approach. The first officer became increasingly alarmed by the high rate of descent which developed and tried repeatedly to alert the captain, eventually resorting to hitting him to try and get him to break out of his trance-like state. It was only when the aircraft broke clear of cloud that the captain recovered enough to pull up, narrowly missing a building. This was not the first time this captain had succumbed to a state of "behavioural inaction" and the crew was very fortunate to survive (event 5b later in this thesis).

Another incident involved a Swissair MD-11 that suffered a cockpit fire shortly after commencing a transatlantic crossing. While initially the smoke was reasonably light, the crew was sufficiently concerned about it to commence a divert; however, denying the urgency of the situation to themselves, they initially elected to divert to Boston, nearly an hour away. When the air traffic controller offered them Halifax as a diversion airport they accepted this in preference, but in a state of further denial, never made any attempt to divert in an expeditious manner, instead opting to hold to the south of the airport so that they could dump fuel, despite the intensity of the fire becoming critical. Even when all their primary instruments failed and the flight deck was immersed in dense smoke, they persisted with their plan to dump fuel and to allow the cabin to be readied. A short time later they were overcome by the fire and the aircraft crashed into the sea (TSB Canada, 2001).

The three inappropriate or ineffective behaviours displayed by these pilots were directly causal in either accidents or near-accidents, and while the Swissair aircraft did have a fault, the other two cases involved perfectly serviceable aircraft. When examining other aircraft accidents and incidents described in the aviation accident literature, it becomes apparent that the prevalence of startle, freezing and denial has been largely ignored until recently. These pathological behaviours have, it appears, been contributory in many accidents, and yet the only behaviour which has received any considered attention is startle, principally in the Colgan Air Flight 3407 and Air France Flight 447accidents (BEA, 2012; NTSB, 2010). Further investigation into these phenomena is warranted.

1.2 The Nature of Startle

The startle reaction has been defined as "a complicated involuntary reaction to a sudden unexpected stimulus (especially a loud noise); involves flexion of most skeletal muscles and a variety of visceral reactions" (The Free Dictionary, 2013). Research into startle commenced in the 1930s on the actual reflex itself (Landis & Hunt, 1939), but it wasn't until some years later (e.g., Thackray & Touchstone, 1970; Vlasek 1969, Woodhead, 1959, 1969) that the further effects of startle became of interest to laboratory researchers. While the startle reflex was of mild medical interest, of more interest were the changes that escalated beyond the reflex, which manifest themselves with the "fight or flight" reaction (Cannon, 1929; Johnson, Kamilaris, Chrousos, & Gold, 1992; Kalat, 2001). This reaction, which occurs when there is some perception of fear or threat, activates several physiological systems in the body, arousing the sympathetic nervous system, inducing an increased heart rate, increased respiration rate, dilated pupils and the introduction of adrenaline (epinephrine) into the bloodstream (Cannon, 1929; Kalat, 2001). This reaction appears to be an evolutionary adaption across a range of species in order to equip those organisms to deal with a threat by fighting it off or running away (Cannon, 1929).

As well as these physiological changes, researchers (e.g., Davis, 1984, 1992; Thackray & Touchstone, 1970; Vlasek 1969, Woodhead, 1959, 1969; Ziperman & Smith, 1975) started to examine the cognitive effects that occurred following startle. The discovery that rats, then other species, could be conditioned to become fearful after some training where a conditioned stimulus was paired with an unconditioned stimulus, allowed researchers to study the effects of *fear-potentiated startle* in a controlled manner (e.g., Davis, 1992, 2001; Grillon, Ameli, Woods, Merikangas, & Davis, 1991; Lang, Bradley, & Cuthbert, 1990; Vrana, Spence, & Lang, 1988). What researchers continue to discover using these techniques is that when a startling stimulus is introduced in conjunction with another stimulus, which has been conditioned to be treated as threatening, the effects of the startle are far greater, far more persistent, and likely to involve activation of the sympathetic nervous system. The conditioning process generally involves a light paired to an electric foot shock or similar, and research has shown that it takes very little time for rats (and other animals) to associate the light with pain, such that after a few iterations of paired stimulus, just the illumination of the light will cause a fearful response (Davis, 1992, 2001; Grillon et al., 1991; Lang et al., 1990; Vrana et al., 1988).

This research has allowed the study of fear responses in animals, including *in vivo* within their brains, which has been able to be accurately generalised to humans (Lang, Davis, & Ohman, 2000; Milad, Rauch, Pitman, & Quirk, 2006; Preuss, 1995; Whalen & Phelps, 2009). Similarities in these species have allowed researchers to study the effects of fear learning on different brain and body parts, and to replicate the results with some validity.

Humans have also been studied directly (e.g., Thackray & Touchstone, 1970; Vlasek 1969, Woodhead, 1959, 1969), with results showing that, where a subject was exposed to a strongly startling stimulus (often a starter’s pistol or the like), they showed significant deterioration in their cognitive ability and psychomotor performance. Tests showed significant delays in reactions following startle, decreased psychomotor accuracy, and impaired ability on cognitive tasks for up to 30 seconds following the startle (Thackray, 1988; Thackray & Touchstone, 1970; Vlasek 1969, Woodhead, 1959, 1969).

Of critical significance is the distinction between a simple startle reflex, from which recovery may occur in less than 1.5 seconds, and fear-potentiated startle, which results in the activation of the arousal system. Considerable research has been done on variations in startle intensity with results showing considerable variance in the level of startle (e.g., Anthony, 1985; Cook, Hawk, Davis & Stevenson, 1991; Davis, 1984, 1992; Graham, 1975; Greenwald, Bradley, Cuthbert, & Lang, 1991; Grillon & Davis, 1995; Grillon et al., 1991; Haerich, 1994; Hamm, Greenwald, Bradley, & Lang, 1993; Hoffman & Ison, 1980; Kalat, 2001; Lang et al., 1990; Silverstein, Graham, & Bohlin, 1981; Simons, 1996; Vrana et al., 1988).

In light of the research on startle, the inappropriate, ineffective, or totally inactive type behaviours, which people have displayed over recent years in accidents and incidents, may have been caused, at least in part, by the deleterious effects on cognition and psychomotor performance following their sudden, unexpected exposure to a startling and fearful stimulus. It is possible that a strong, fear-potentiated startle, which has been replicated repeatedly in the laboratory, may have contributed to the adverse reactions experienced in the Colgan accident and others (e.g., NTSB, 2004, 2005, 2007, 2010).

The effects of startle on pilot performance is examined in detail in the following chapters. This research involved investigation of incidents and accidents from history, discussion of the effects on pilots who have experienced startle, and examination of the effects of startle in a flight simulator experiment.

1.3 The Nature of "Freezing"

The concept of "freezing" is widely understood. It was defined by Phillips and LeDoux (1992) as "the suppression of all movement except that required for respiration" (p276). several manifestations of "freezing-like" behaviour are described in the literature. Catatonia, dissociation, catalepsy, tonic immobility, cognitive inaction, mental disengagement, cognitive overload, and dissociation are all terms that refer to behaviours where no action is taken for some reason. They each describe a state where a person (or animal in some cases) displays complete and pathological inactivity. Catatonia, catalepsy and dissociation are terms widely used in describing psychiatric conditions (Lynn & Rhue 1994; Misslin, 2003; Taylor, 1990), while tonic immobility is akin to "playing dead", a survival response observed in animals of prey, but also in humans in rape and abuse incidents (Bados, Toribio, & Garcia-Grau, 2008; Bracha et al., 2004; Heidt, Marx, & Forsyth, 2005; Misslin, 2003; Moskowitz, 2004). Cognitive inaction, cognitive overload and mental disengagement are all cognitive constructs which are associated with excessive concurrent task demand, or an overwhelming of the working memory by too much high priority or stressful information (Barrouillet, Bernardin, & Camos, 2004; Byrne & Anderson, 2001; Carver, Peterson, Follansbee, & Scheier, 1983; Cowan, 1999; de Jong, 1993; Lazarus, 1966; Lemaire, 1996; Matthews & Campbell, 2009; Matthews, Sparkes, & Bygrave, 1996; Oberauer & Göthe, 2006; Pashler, 1994; Wickens & Weingartner, 1985).

The term chosen in this thesis to describe this frozen condition is *behavioural inaction* (Lazarus, 1966; Muir et al., 1996). This is related to cognitive inaction, but manifests itself to other people as simple inactivity at a time when there should be something happening. An analogy of this state is with a public speaker who is unable to speak, frozen by an acute stress reaction which is self-perpetuating. The longer they go without speaking, the more stressed they become, until some external intervention or distraction saves them. Observers of people in this state often describe a person fixated or staring straight ahead, and in a couple of the incidents discussed later in this paper, has also included a vice-like grip, which has been very difficult to overcome (see events 5b and 35b later in this thesis).

Stress has been shown by Canon (1929), Selye (1956) and others (e.g., Kalat, 2001), to engender some significant changes in the body. Indeed, the fight or flight response discussed earlier has been more widely associated with stress than with startle, but it is effectively the same process as that enacted by fear-potentiated startle (Bracha et al., 2004; Davis, 1992; McEwen, 2007). This process physically alters the bodily systems and introduces approximately 30 hormones and chemicals into the bloodstream, the most notable ones being epinephrine (adrenaline) and cortisol (Kalat, 2001; Marmot & Wilkinson, 2009).

Of most concern in the aviation paradigm, however, are the cognitive effects of stress, and particularly acute stress, that arise when individuals are rapidly exposed to a situation with which they perceive they are unable to cope. This has been shown to manifest itself cognitively by a reduced ability to process information, impaired decision-making, impaired situational awareness and breakdowns in other social skills (Ashcraft & Kirk, 2001; Baddeley, 1972; Campbell & Bagshaw, 2002; Canon-Bowers & Salas, 1998; Diaz, Hancock, & Sims, 2002; Driskell & Salas, 1996; Driskell, Salas, & Johnson, 1999; Griffin & Rockwell, 1987; Hammond, 2000; Hancock & Szalma, 2008; McEwen & Sapolsky, 2005; Matthews, Davies, Westerman, & Stammers, 2000; Staal, 2004; Wickens, 1984).

The incident mentioned earlier (event 5b), in which the captain of an aircraft “froze” at the controls, was a fairly severe manifestation of this behavioural inaction and the incident could easily have had severe consequences. The totally inactive state that he had entered appears to have been associated with a ramping up of the stress levels he was experiencing, associated with the aircraft entering cloud. This incident and others in which people have suffered behavioural inaction are discussed in depth in chapters three and four.

1.4 The Nature of Denial

Numerous researchers, starting with both Sigmund and Anna Freud (Freud, A., 1936; Freud, S., 1962, 1966), have examined the ways that people manage stress. The Freuds and others (e.g., Cramer, 2000, 2006; Vaillant, 1992, 1994) have described a defence mechanism as one means that individuals use to deal with stress.

Denial has been defined from a psychological perspective as “a psychological defense mechanism in which confrontation with a personal problem or with reality is avoided by denying the existence of the problem or reality” (Merriam-Webster, 2013). This process employs one or more strategies to lower stress internally, allowing a state of homeostasis to resume (Canon, 1929; Cramer, 2006). Techniques such as disavowal of reality, avoidance, or denial are commonly quoted as defence mechanisms which individuals use to remove a stressor from their thoughts in order to alleviate stress (Lazarus, 1966, 1998; Wheeler & Lord, 1999).

Research by Lazarus and others (e.g., Folkman & Lazarus,1980, 1993; Folkman, Lazarus, Gruen et al., 1986; Folkman & Moskowitz, 2004; Lazarus, 1999; Lazarus & Folkman, 1984; Monat & Lazarus, 1991) has also viewed these mechanisms as coping tools, rather than as defensive mechanisms. Folkman & Lazarus (1980) described a process where primary appraisal is made of all new stimuli, to ascertain any element of threat or danger (Lazarus & Folkman, 1984). Where some threat is perceived, then Lazarus and colleagues described a secondary appraisal process in which the organism determines what to do about this new stressor (Folkman & Lazarus, 1980, 1993; Folkman et al., 1986; Folkman & Moskowitz, 2004; Lazarus, 1999; Lazarus & Folkman, 1984; Monat & Lazarus, 1991). Folkman & Lazarus (1980) suggest two options: either a problem-focused coping technique is used to alter or remove the stressor, or, where the stressor can’t be fixed, some emotion-focused technique is employed (Billings & Moos, 1981; Lazarus & Folkman, 1984a, 1984b; Lazarus & Laurier, 1978; Monat & Lazarus, 1991). Coping generally involves the same techniques mentioned in defence mechanisms: disavowal of reality, avoidance or denial (Lazarus, 1989; Wheeler & Lord, 1999).

The literature therefore contains two very similar concepts describing sometimes identical techniques for alleviating stress. Indeed, both defence mechanisms and coping processes seem almost interchangeable in the literature. Cramer (2000) tried to delineate the two terms, describing defence mechanisms as more stable, unconscious traits, while coping processes are more dynamic, conscious and situational.

This delineation is useful also on a temporal basis. While most denial research has been in the medical field (e.g., Croog, Levine & Lurie, 1968; Croog, Shapiro & Levine, 1971; Lazarus, 1981; Ness & Ende, 1994; Shelp & Perl, 1985; Vos, 2009; Vos & de Hayes, 2007), often looking at how people deny the reality of potentially fatal diseases, there is less real-world research on the more short-term coping processes which people apply when suddenly confronted with threatening information. It would therefore be appropriate to break denial (as a subset of both defence and coping) into long-term, strategic denial, and short-term, tactical denial. The latter is the subject of this study, which focuses on identifying those situations where denial may have been employed as a tactical coping mechanism. It is hypothesised that pilots, when confronted with a threatening situation where no obvious fix exists, use denial as a means of alleviating the acute stress which is generated.

Breznitz (1983) described seven different stages of denial. These included denial of affect relevance, denial of affect, denial of responsibility and/or vulnerability, denial of urgency, denial of personal relevance, denial of threatening information, and finally, denial of information. The scale is a one-way Guttman[1] scale of increasing denial, which will be used as an analysis tool when addressing incidents and accidents in chapter 4. It is hypothesised that where higher levels of denial are used by individuals in critical situations, then the chances of a situation deteriorating are quite high.

1.5 Research Question

The research question to be addressed in this study is:
"*Can behaviours such as startle, freezing and denial during aircraft emergencies or unexpected critical events impact on flight safety?"*

Each of these three behaviours are potentially pathological when they induce inappropriate, ineffective, or inaction type behaviours following critical or unexpected events.

There have been some high profile accidents and incidents over the last few years in which pilots have inexplicably performed less than optimally, even when confronted with easily

[1] A Guttman Scale describes a cumulative scaling process where a given score incorporates all lower scores (Social Research Methods, 2006). In this case, high-level denial would include behaviours described in the lower levels of denial.

managed situations. Air France Flight 447 (BEA, 2012), Colgan Air Flight 3407 (NTSB, 2010), and Turkish Airlines Flight 1951 (Dutch Safety Board, 2010) are just three examples of flights where the pilots were suddenly confronted with an unexpected critical event. In each case the recovery from an undesired state (Merritt & Klinect, 2006) was mismanaged badly and resulted in catastrophic accidents.

It was the intent in this thesis to examine these accidents and others for instances of startle, freezing or denial to determine whether these contributed to any negative outcome. The study included incidents gleaned from personal accounts described in interviews with pilots who have experienced critical events. It also examined aircraft accident and incident reports in the public domain for evidence of these pathological behaviours.

Having established the presence of startle, freezing and denial in these accidents, a flight simulator experiment will be discussed with the intention of quantifying the scope of cognitive disruption experienced during startle. While the experiment would ideally also quantify the effects of acute stress, the level of stress needed to generate freezing or denial type behaviours could not be produced in an ethically acceptable manner. As a result, startle is the only measurable phenomenon which can be generated.

The research will therefore answer the following question: can “startle”, “freeze” and “denial” be significant enough pathological behaviours to affect flight safety?

1.6 Thesis Outline

This study will start by examining the literature. The diversity of the three phenomena being studied necessitates a wide search, and considerable time is spent detailing the workings of the brain, particularly under conditions of fear and stress.

Chapter three examines the methodologies used in this study. The principal methodology is qualitative, relying on qualitative data analysis from the data obtained and from pilot interviews. However, a quantitative element exists in the flight simulator research. The simulator performances of each participant will be subjected to both statistical and qualitative analysis to establish the significance of startle on situation outcome. This mixed methods research will be described in some detail.

Chapter four will describe 29 incidents and accidents from database searches and accident reports using a criterion-based case study methodology. These incidents and accidents will be analysed qualitatively for instances of startle, freeze and denial, and any discernible effects these phenomena had on situation outcome.

Chapter five will describe 26 incidents and accidents which were gleaned from interviews with pilots who had experienced critical events. These events will be analysed qualitatively for instances of startle, freeze and denial, and any discernible effects these phenomena had on situation outcome.

Chapter six will describe a startle experiment in a Boeing 737 flight simulator using current, type rated pilots. The results of the experiment will be analysed both qualitatively and quantitatively for effects resulting from startle during a critical phase of flight.

Finally, chapter seven will discuss startle, freezing and denial based on the findings and results. Conclusions will be made on the effects these behaviours have had in critical events, and the research question will be addressed. Future research required will also be discussed.

CHAPTER 2 LITERATURE REVIEW

2.1 Stress

The freezing and denial phenomena which were introduced in chapter 1 are largely coping mechanisms for dealing with acute stress. Similarly, while startle may start out as a simple reflex action, persistent threat often results in a full stress reaction developing in those affected. It is appropriate therefore to devote some attention to the nature of stress, to define it and to further examine its effects.

2.1.1 The Nature of Stress

All three pathological behaviours being considered in this thesis are related to stress. Both freezing and denial are stress coping or defence measures, while startle, in the presence of fear or threat, engenders a stress response in the body. It is worthwhile therefore, examining the nature of stress in general, before addressing startle, freeze and denial individually.

Stress is a fundamental component of the human make-up. It manifests itself physically, emotionally, and psychologically, and can be both positive and negative in its effects. Manifestations of stress may be systemic or social (Monat & Lazarus, 1995) with systemic stress due to tissue system disturbance and social stress being a disturbance of a social unit or system. Stress may involve phenomenological experiences (Wickens & Hollands, 2000) (often with emotional or affective responses), physical responses such as increased heart rate (Hart & Hauser, 1987) or raised catecholamine levels (Bourne, 1971; Burton, Storm, Johnson, & Leverett, 1977, McEwen, 2007), and effects on information processing (Bishop, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007; Eysenck, Payne, & Derakshan, 2005; MacLeod, 1996; Maule & Hockey, 1993; Raley, Stripling, Kruse, Schmorrow, & Patrey, 2004; Salthouse, 2012; Wickens & Hollands, 2000).

Stress is not necessarily something bad; it all depends on how an individual perceives it (Lazarus, 1966). The stress of exciting challenges or creative and successful work is beneficial, while that of being over-taxed mentally, failure, or humiliation is generally detrimental. The original conception of Holmes and Rahe (1967) was that any change, whether positive or negative, was stressful, because change events make adaptational demands, although negative events have subsequently been shown to have a greater role in illness (Lazarus, 1999) and ageing (McEwen, 2007).

Stress is generally considered the body's response to some type of psychological or environmental stressor (Lazarus, 1966; Selye, 1956). Such stressors may include influences of environmental entities such as noise, vibration, heat, dim lighting, and high acceleration (Wickens & Hollands, 2000). Psychological stressors include factors such as anxiety, fatigue, frustration, anger, and time pressure (Svenson & Maule, 1993; Wickens & Hollands, 2000).

Stress research dates back as far as Sigmund Freud (1894-1962), who popularised the concept of defence as a set of psychological mechanisms which individuals use to distort reality to manage distressing feelings, particularly anxiety (Costa, Zoederman, & McCrae, 1991; Cramer, 1998, 2000; Freud, 1920, 1924; Parker & Endler, 1996; Somerfield & McCrae, 2000).

Stress was initially defined by Hans Selye as "the non-specific response of the body to any demand" (Selye, 1956, p. 55). Considerable work has been done since Selye's ground breaking research, particularly that of Lazarus and colleagues (e.g., Lazarus, 1966, 1990, 1999; Lazarus & Cohen, 1977; Lazarus & Folkman, 1984b; Lazarus & Launier, 1988; Monat & Lazarus, 1991). While there are occasional references to stress as a positive thing (e.g., Wickens, 1984), the majority of literature defines stress in a more negative manner, largely in terms of deficits brought on by environmental demand. Some definitions offered in the literature include those by:

- Lazarus and Folkman (1984b) who described stress as "...a relationship between the person and the environment that is being appraised by the person as taxing or exceeding his or her resources and endangering his or her well being" (p. 19);
- Kroemer & Grandjean (1997), who suggested that it is "the emotional state or mood which results from a discrepancy between the level of demand and the person's ability to cope" (p. 212);
- Weiten (2010) who defined stress as, "circumstances that threaten or are perceived to threaten one's well being and that thereby tax one's coping abilities" (p. G9);
- The UK Health and Safety Executive (2012), which defined stress in a work environment as "the adverse reaction people have to excessive pressure or other types of demand placed on them" (p. 1);
- Cohen, Kessler, and Gordon (1995) suggested that stress may be defined as "demands which tax or exceed the adaptive capacity of a being, resulting in physiological and/or psychological changes in that individual" (p. 15); and

- Rash and Manning (2009) further suggested that stress is “a response to demands placed upon the human body; the response to which can be physical, psychological or physiological” (p. 38).

A more lengthy definition (which is used to define occupational stress), suggests stress is “the emotional state or mood which results from a discrepancy between the level of demand and the person’s ability to cope. It is thus a subjective phenomenon and exists in people’s recognition of their ability to cope with demands of the work situation” (Kroemer and Grandjean, 1997, p. 212).

McGrath (1976) cited in Stokes and Kite (1994) offers a slightly more transactional view. He defined stress in terms of *three* elements: perceived demand, perceived ability to cope, and perception of the importance of coping - that is, the extent to which the demands of the situation threaten the goals or aspirations of the individual.

2.1.2 Models of Stress

Various models of stress exist. The three principal models are the Stimulus Model, the Response Model and the Transactional Model (Lazarus & Folkman, 1984b; Stokes & Kite, 1994).

2.1.2.1 Stimulus-Based Approaches

For many decades stress research was fundamentally based on the conception of stress as a study of external events, rather than on the subjective experience itself (Stokes & Kite, 1994). This approach simply labelled variables which were assumed to be aversive as *stressors* and research simply manipulated the supposedly aversive variables (O’Driscoll, Cooper & Dewe, 2001). Such variables included time pressure, noise or workload, and applied research has largely consisted of manipulating a selected variable under the guise of inducing stress (O’Driscoll et al., 2001; Selye, 1976; Stokes & Kite, 1994), regardless of whether the manipulated variable actually created a feeling of stress in the individual concerned (Stokes & Kite, 1994). This simplistic approach has been widely criticised because stress becomes “merely a convenient label and collective noun indicating certain environmental and organismic conditions” (Sanders, 1983, p. 62).

One of the major failings of the stimulus-based approach is that it fails to recognise the different effects it may actually have on individuals. Both the emotional component of experiences and individual differences are ignored (O’Driscoll et al., 2001; Stokes & Kite, 1994).

2.1.2.2 Response-Based Approaches

In contrast to stimulus-based views of stress, response-based approaches focus not on the external circumstances assumed to induce stress reactions but on the reactions themselves (O’Driscoll et al., 2001; Selye, 1978; Stokes & Kite, 1994). In this model, the actual effects define the stress unrelated to any given stressful variable. This approach has its roots in research conducted in the early 1900s by Yerkes and Dodson; however, Selye (Selye, 1956) was perhaps the largest influence on the response-based approach. Selye, who was studying physiological responses to injury, emotion, and intense stimuli, observed that while some of these reactions were clearly linked to particular stimuli, others seemed to be less specific and appeared in a wide variety of aversive or demanding situations (Stokes & Kite, 1994). This latter group included increases in heart rate, respiration, adrenaline and other metabolic and endocrine functions associated with autonomic nervous system activity (Stokes & Kite, 1994).

Selye (1946, 1950) proposed a response-based approach to stressors which he termed the “*General Adaption Syndrome*”. This “syndrome” linked an increase in *arousal* or energetical state of an organism to stress, largely determined by physiological changes in the body (Selye, 1950). Selye regarded the reaction to stressors to be a systemic, non-specific adaption which prepared the individual to deal with an untoward threat (Selye, 1946, 1950). This non-specific response was what caused him to describe the syndrome as “general” (Stokes & Kite, 1994).

Response-based research has largely addressed the physiological changes which accompany elevated arousal levels (O’Driscoll et al., 2001; Stokes & Kite, 1994). Such changes typically come about through activation of the sympathetic nervous system which initially stimulates the adrenal medulla, located near the kidneys, to release the adrenaline-like compounds, epinephrine and norepinephrine, into the bloodstream (McEwen, 2007). The hypothalamus also signals the pituitary gland near the brainstem to create other chemical signals (e.g., CRH and ACTH) to help further activate the body (McEwen, 2007; Stratakis & Chrousos, 1995). As a result of action on the pituitary, the adrenal cortex releases cortisol, which is important for maintaining increased blood sugar levels for energy (McEwen, 2007; Ulrich-Lai & Herman, 2009). An increased heart rate is achieved through the release of epinephrine (adrenaline) and increased motor response through norepinephrine being released. (Charney, 2004). Figure 1 illustrates the relationship of the various components within the brain and the sympathetic nervous system during the typical stress response. This response is commonly referred to as the fight or flight response (Bracha et al., 2004; Canon, 1929; McEwen, 2007).

Image removed

Figure 1 - The Stress Reaction (Fight or Flight)
(Adapted from cpmedical.net)

Different techniques have been used to measure stress responses (Stokes & Kite, 1994). These include:

Subjective:	Ratings and protocols of how the person feels, how well he believes he is doing. Confidence/anxiety reports.
Behavioural:	Objective measures of performance change on "real world" tasks or specialised performance tests, including computerised test batteries and instrumented flight simulators.
Psychophysiological:	Objective measures of variables such as heart rate, muscle tension, galvanic skin response (skin conductance), respiratory rate, etc.
Biochemical:	Objective measures of neurotransmitters and their metabolites, e.g.,, serotonin, epinephrine, norepinephrine, dopamine (Stokes & Kite, 1994).

Both the stimulus and response approaches to stress research lack a cognitive appraisal element (Folkman, Lazarus, Dunkel-Schetter, DeLongis, & Gruen, 1986; Lazarus & Folkman, 1984b; Lazarus & Laurier, 1978; Stokes & Kite, 1994). Neither view has an element of personal perception of threat, which is generally influenced by an individual's purposes, goals, and personal interpretations of particular situational contexts. As a result of this void, modern stress research has trended towards more of a transactional approach, looking more at stimulus, response and the transaction with the environment rather than simply stimulus or response (Lazarus & Launier, 1978; Stokes & Kite, 1994).

2.1.2.3 Transactional Approaches

Unlike earlier models, transactional models conceptualise stress as a transaction between the person and their environment, and are reliant on personal interpretation of an encounter (Harris, 1991; Stokes & Kite, 1994). Stokes and Kite (1994) suggest that these encounters have affective meaning because each individual has "beliefs, goals, hopes and fears, while the environment imports threats, challenges, opportunities and risks" (p. 12). They further suggest that the core of the stress response lies in the evaluation of stressors and coping options within a personal framework of motivations and agendas (Stokes & Kite, 1994). Transactional approaches are commonly referred to as "Person-Environment" (P-E) approaches to stress research (e.g., Edwards & Cooper, 1990; Harrison, 1978; Lazarus & Launier, 1978).

Increasingly, transactional models that incorporate cognitive appraisal as a necessary element in human performance and information processing are becoming widely accepted (e.g., Folkman et al., 1986; Lazarus & Folkman, 1984b; Lazarus & Laurier, 1978). Many studies have demonstrated that evaluations of threat and/or controllability are clearly related to the experience of subjective distress (e.g., Folkman & Lazarus, 1980, 1985; Folkman, Lazarus, Dunkel-Schetter, DeLongis & Gruen, 1986; Lazarus, 1966, 1981; Leach, 2004; Matthews & Campbell, 2009). To what degree these evaluations are also directly related to improvements or decrements in performance is less clear. In general, negative appraisal often leads to negative outcome while positive appraisal appears to improve task performance (it reduces subjective distress as well as objective performance) (Lazarus & Folkman, 1984b). When this evaluation occurs and at what level of cognition remains undecided, but much of the research seems to point to an initial early evaluation followed by a more involved higher-order cognitive process (Lazarus & Folkman, 1984b; Skinner & Brewer, 2002; Terry, 1991; Zohar & Brandt, 2002). The main purpose of this initial evaluation appears to be a preparatory one, facilitating the quick orientation and organisation of the individual's response to the stimulus (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991).

The psychological meaning a person constructs about an environmental event is the underlying cause of the stress reaction and the emotions it produces (Jessor, 1981; Lazarus, 1966, 1991). When an individual perceives that they are able to cope with the demands of a situation then stress is unlikely, however, when they perceive that the demands of the task or situation are greater than the individual resources they have to cope with them, then stress is likely (Folkman & Lazarus, 1984b; Folkman et al., 1986; Lazarus, 1966, Stokes & Kite, 1994).

The key issue in the transactional model is appraisal, which may occur repeatedly following introduction of a stressor (Lazarus & Folkman, 1984b). First, the potential stressor is evaluated in terms of its capacity to do harm, and then sub-evaluations are made about novelty, certainty, and predictability (Lazarus & Folkman, 1984b). Importantly, the stressor is also construed as either a threat or a challenge (Monat & Lazarus, 1991). Having then appraised a stressor, the individual then appraises their own ability to handle this stress or challenge, and the strategy most likely to reduce the potential harm (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991).

Unlike stimulus or response-based approaches, transactional models emphasise the role of cognitive appraisal in determining whether stimuli are stressful or not (Stokes & Kite, 1994). As such they are more psychological than the two earlier approaches, and emphasise the mental processes which mediate an individual's reactions (Folkman & Lazarus, 1984b; Lazarus, 1966, 1991, 1998; Stokes & Kite, 1994). A further analysis of the appraisal process is warranted to explain this transactional approach.

It is clear from the stress research that an evolving picture of what stress is, and how it can be measured and analysed, has unfolded over the last century or so. It is now acknowledged widely by researchers that stress is a transactional process, which is dependent on the person involved and the nature of their interaction with their environment on the day. Further research in this field is warranted.

2.1.3 Appraisal

Cognitive appraisal is an evaluative process that occurs within each individual. It determines why and to what level a particular relationship between the person and the environment is considered stressful (Lazarus & Folkman, 1984b). An event may be appraised as stressful based on its importance (Carver, Scheier, & Weintraub, 1989) or in terms of its controllability (Folkman, 1984) and is dependent on one's values, beliefs, good commitments and situational intentions (Lazarus, 1999).

Appraisal partakes of cortical information processing, but is not considered normal information processing per se; rather, it is broadly evaluative, focussing on the meaning or significance to the individual, and takes place continuously throughout peoples' lives (Lazarus & Folkman, 1984b). Zajonc (1980) suggested that this evaluative process is independent of cortical processing, occurring in far less time than the normal 500+ ms required for retrieval processing (Åsli & Flaten, 2012), with both novel and well learned stimuli. Other research (e.g., Bargh, Chaiken, Govender, & Pratto, 1992; Bargh, Chaiken, Raymond, & Hymes, 1996; Fazio, Sanbonmatsu, Powell, & Kardes, 1986) supports this concept of rapid and automatic evaluation.

Appraisal may be deliberate and largely conscious, or an intuitive, automatic, and unconscious process (Lazarus & Folkman, 1984b). Sometimes appraisal requires a slow, deliberate search for information to determine how we should react, especially about what can be done to cope with the current situation, while at other times, we must make a very rapid appraisal (Monat & Lazarus, 1991). Zohar and Brandt (2002) also found that selective attention may shape the appraisal, with the most salient stressor capturing an individual's attention, which in turn mediates how that situation is appraised (Staal, 2004).

Lazarus and Folkman (1984b) suggested that by the time we are adults, most appraisals are rapid or instantaneous because the situation has already been experienced previously. This obviates the need for a full appraisal, resulting in a rapid evaluation. A previously experienced threatening situation therefore may result in a rapid onset of the stress reaction and its associated coping process, without the need for reflection on the situation or new learning (Lazarus & Folkman, 1984b).

There are two conceptually different types of appraisal: primary appraisal, where an evaluation is made of whether a situation is relevant or threatening, and secondary appraisal, where attention is focused on what we can do about it (Folkman et al., 1986; Lazarus & Folkman, 1984b). These processes are not necessarily chronological in order, however they are largely interdependent, with each ongoing primary and secondary appraisal process being affected by the other (Lazarus & Folkman, 1984b).

Furthermore, Lazarus & Folkman (1984b) suggest that three kinds of primary appraisal may be established:

- appraisal that a situation is irrelevant and therefore has no implication for well-being;
- appraisal that a situation is benign or positive; and

- a stressful appraisal that the possibility for harm/loss, threat or challenge exists.

A study by Zakowski, Hall, Cousino, Klein, and Baum (2001) found that the coping strategies chosen by individuals tended to match their appraisals of stress controllability. Skinner and Brewer (2002) agreed, asserting that viewing an event as challenging rather than threatening generally results in improved emotion-coping styles, positive feelings, and greater confidence. This confidence equates to a sense of self-efficacy—a feeling of being able to cope with a particular situation (Endler, Speer, Johnson, & Flett, 2001). Endler et al. (2001) found individuals' ratings of self-efficacy, their perception of their own ability to affect change, was a better predictor of anxiety than their perception of control over the stressful situation.

The level of self-efficacy perceived reflects a person's appraisal of his or her ability to deal with a situation (Bandura, 1977; Lazarus & Folkman, 1984b). Bandura (1977) further claimed that self-efficacious individuals are more inclined to focus on task requirements, while individuals with low levels of self-efficacy are more likely to focus on their perceived inability to master a situation, leading inevitably to stressful appraisals.

Appraisal is a continuous process and reappraisals of existing situations may be modified as the situation changes or as interpretation of that situation changes (Lazarus & Folkman, 1984b). Appraisals are not singular, but work with continuous variables, varying the emotional response according to the person-environment interpretation. This continual reinterpreting of situations may lead an initial stress appraisal to be reappraised as simply challenging, or conversely, an initially benign situation being reappraised as stressful (Lazarus & Folkman, 1984b). Appraisal research has shown this process to be an evaluative one, which is rapid and ongoing. Transactional in its foundation, appraisals are dependent on a person's experience and the nature of the their environmental stimuli at the time.

2.1.4 Coping Mechanisms

Coping is defined as "constantly changing cognitive and behavioural efforts to manage specific external and or internal demands that are appraised as taxing or exceeding the resources of the person" (Lazarus & Folkman 1984b, p. 141). It is the process through which each individual manages the demands of the situation they are encountering that are appraised as stressful, and the emotions they generate (Lazarus & Folkman, 1984b). Coping consists of efforts by an individual to overcome the demands that are appraised as exceeding or taxing that person's resources (i.e. conditions of harm, threat or challenge) (Monat & Lazarus, 1991).

Lazarus & Folkman (1984b) also suggest that coping is a process-oriented, situational construct, rather than a trait-oriented method of dealing with stress, and that effective coping generally involves selecting the best coping mechanism which meets the fit of situational demands and individual needs. The coping strategies that an individual chooses to utilise in a particular situation will be determined by their coping resources (which are relatively stable characteristics of a person's disposition and also of the social environment) and their appraisal of the event (Terry, 1991).

Lazarus and Folkman (1984b) further suggest that there are three key aspects to determining the coping methods employed. Firstly, coping is *process-oriented* in that it is focused on what an individual thinks and does during a stressful encounter and any changes to this process as the situation unfolds. Second, it is entirely *contextual* in that it is dependent on each individual's appraisal of actual demands and their resources for dealing with them. Coping efforts in this respect will be shaped by both the individual and the demands of the situation. Finally, coping may not be successful. It is simply defined as the process which an individual goes through to try and manage a stressful encounter (Lazarus & Folkman, 1984b).

White (1974) tried to delineate coping under three separate functions:

- to keep securing adequate information about the environment,
- to maintain satisfactory internal conditions both for action and for processing information, and
- to maintain autonomy or freedom of movement, and freedom to use one's repertoire in a flexible fashion (p. 55).

Later research, however, has generally led to two major functions of coping being widely acknowledged. These are regulating stressful emotions (through techniques called emotion-focused coping), and altering the individual's relationship with the stressor so as to remove or reduce distress (problem-focused coping) (Lazarus, 1999; Lazarus & Folkman, 1984b; Monat & Lazarus, 1991). When conditions are appraised as changeable and controllable, then problem-focused coping generally dominates. Conversely, when conditions are appraised as unchangeable or beyond a person's control, then emotion-focused coping predominates (Lazarus, 1999; Lazarus & Folkman, 1984).

Separate studies by de Longis, Folkman and Lazarus (1988) and Folkman and Lazarus (1980) showed that around 97% of participants in experiments involving stressful situations employed both problem-focused and emotion-focused coping mechanisms. Indeed, Folkman and Lazarus

(1980) suggest that on average, when confronted with a stressful situation, people use almost all of the eight coping strategies available to them, but noted that some individuals have a propensity to prefer certain strategies. Folkman and Lazarus (1980) note two possible explanations for this, Firstly, stressful encounters are often complex and some trial and error may be necessary to find the most effective mechanism. Secondly, each complex stressful encounter is multifaceted in terms of goals and threats to goals, and each different coping mechanism may be loosely tied to one of these psychological facets (p. 119).

Emotion-focused strategies focus on managing the emotional distress associated with the stressor and include disengaging from emotions related to the stressor, seeking emotional support, and venting emotions (Folkman et al., 1986; Folkman & Moskowitz, 2004). Emotion-focused coping is often used to maintain hope and optimism, to deny both fact and implication, to refuse to acknowledge the worst, to act as if what happened did not matter, and so on (Lazarus & Folkman, 1984b). These processes are somewhat pathological and maladaptive and lend themselves to self-deception, denial or reality distortion (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991). Such processes, in which stressful stimuli or information is ignored or distorted, while quite possibly relieving anxiety, are likely to have significant effects on information processing and other processes such as situational awareness and decision-making.

The following emotionally-focused coping mechanisms have been identified:

- avoidance,
- reality distortion,
- denial,
- self-deception,
- humour,
- venting of emotion,
- behavioural disengagement, and
- mental disengagement (Lazarus & Folkman, 1984b, p. 119)

Lazarus and Folkman (1984b) suggested that reductions in capacities for both information processing and problem-solving during stressful encounters will impair the development of problem-focused strategies. Furthermore they proposed that the emotional distress created in highly stressful situations often necessitates the use of tension-reducing (i.e., emotion-focused coping) strategies (Lazarus & Folkman, 1984b).

When emotion-focused coping mechanisms such as reality distortion, denial or self-deception are employed, then it is probable that information processing will be distorted in some way

(Lazarus, 1982). The model outlined in Figure 2 proposes the typological relationship between appraisal, coping and information processing.

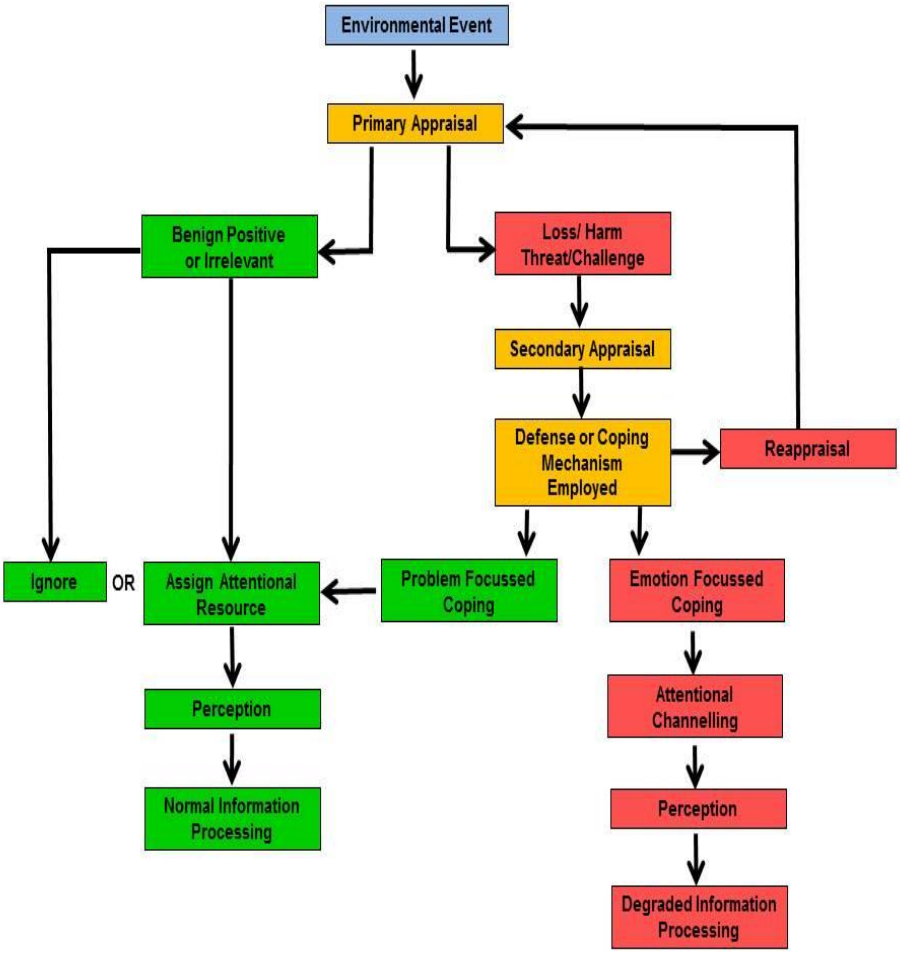

Figure 2: A Conceptual Model of Appraisal, Coping and Information Processing

It is suggested that the model shows the effect of both problem-focused coping methods and emotion-focused coping methods on information processing. When a new stimulus is considered benign, positive, or irrelevant through the primary appraisal process, then normal information processing will likely ensue. Normal attentional resources are applied, or the stimulus is ignored totally. Perceptual processes make sense of the stimulus where necessary and the information is cortically processed in the usual manner.

When the primary appraisal process categorises a new stimulus as possibly threatening or harmful, involving some likely loss or being challenging in its nature, then it engenders a degree of stress, which, through the body's homeostasis or allostasis needs (McEwen, 2007), requires some form of coping mechanism to alleviate that stress. To achieve this, the body employs a secondary appraisal process to determine the coping mechanism(s) best available to deal with the stressor.

Where a problem-focused coping method is available (i.e., some means of actually reducing the stressor), then this may be employed (Lazarus & Folkman, 1984a, 1984b; Monat & Lazarus, 1991). The act of removing the stressor would therefore allow allostasis/homeostasis to resume, with normal information processes working normally. Attentional resources would be assigned normally, perception would be achieved without distortion, and cortical processing would proceed in a typical fashion. This would in turn allow rational processing of options and normal faculties to deal with the external stimuli which existed at the time.

When no immediate problem-focused strategy was obvious, or the stressor was appraised as being overwhelming, then the brain would attempt to reduce the level of stress by employing one or more emotion-focused coping processes. Such processes could include irrational or subconscious efforts to interpret the stressor in a non-threatening manner (Lazarus & Folkman, 1984b). Pathological, emotion-focused coping mechanisms (such as those identified by Lazarus & Folkman, 1984b and Monat & Lazarus, 1991) generally involve escapist or avoidance processes, which may involve the complete disavowal or reality or fact. Such processes would therefore involve selective attention, or attentional channelling away from stressful stimuli perhaps, which in turn degrades the perception of the situation and the cortical processing of that event (Bishop, 2009; Eysenck et al., 2007; Eysenck et al., 2005; MacLeod, 1996; Salthouse, 2012; Wickens & Hollands, 2000).

Notwithstanding the normal continuous appraisal of unfolding environment cues, the model at Figure 2 also suggests that a continual reappraisal process is particularly necessary when emotion-focused methods of coping occur. Because the stressor is not dealt with by some problem-focused method which removes the stress, then the stressor continues to persist and will result in continuous on-going appraisals of harm/loss, threat or challenge (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991). Such reappraisals, when a stressor persisted, would in turn require further secondary appraisals to establish preferred coping methods. This cyclical process would continue until the stressor was removed or the situation was no longer appraised as being threatening, challenging or harmful (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991).

Research by Lazarus and others (e.g., Folkman, 1984; Lazarus, 1966; Lazarus & DeLongis, 1983; Lazarus & Folkman, 1984a, 1984b) has shown that the individual importance attributed to an event is a predictor of coping behaviour and that high levels of threat are likely to be experienced in events considered to be highly important. This may be because the outcome of the event may jeopardise the attainment of a valued goal and the more that an individual has something at stake in an encounter, the more likely they are to experience emotions of threat (Folkman & Lazarus, 1985) or to suffer psychological symptomatology (Folkman et al., 1986).

Terry (1991) also suggested that high levels of importance will detract from an individual's attention to the task and, thus, lessen the likelihood that problem-focused strategies will be utilised, thereby heightening the necessity for emotion-focused strategies. Research by Hockey (1997), Hockey, Gaillard, and Coles (1986) and Robert and Hockey (1997) further describes how stressed individuals may psychologically lower their standards for adequate performance so that a lowered level of performance is judged acceptable, with strategy change becoming a direct outcome of choice of coping. Strategies of this kind may also be described as *avoidance*, such that the person deals with the problem by mentally withdrawing from it (Matthews, Davies, Westerman & Stammers, 2008).

While the distinction between problem-focused coping and emotion-focused coping exists widely in the literature, an alternative distinction is also discussed. While conceptually similar to problem- and emotion-focused coping, other researchers have emphasised a distinction between *approach* and *avoidance* concepts in coping strategies (e.g., Snyder & Pulvers, 2001; Tobin, Holroyd, Reynolds, & Wigal, 1989).

Approach strategies are focused on the stressor itself or one's reaction to it and are generally regarded as more adaptive (Snyder & Pulvers, 2001). Some examples include seeking emotional support, planning to resolve the stressor, and seeking information about the stressor (Tobin et al., 1989). In contrast, avoidance strategies are focused on avoiding the stressor or one's reaction to it; for example, withdrawing from others, denying that the stressor exists, and disengaging from one's thoughts and feelings regarding the stressor (Snyder & Pulvers, 2001; Tobin et al., 1989).

Some have also argued that approach and avoidance strategies should be further subdivided (Tobin et al., 1989). One possibility is to attempt to integrate these two conceptualisations of coping by subdividing approach and avoidance strategies into problem/behavioural or emotion/cognitive strategies (Snyder & Pulvers, 2001; Tobin et al., 1989). Strategies focused on solving the problem would then be labelled as *problem/behavioural approach* (e.g., planning how to resolve the stressor, seeking information about the stressor) and those focused on actively managing one's emotions or thoughts about the stressor would be labelled as *emotion/cognitive approach* (e.g., attempting to restructure cognitions about the stressor, seeking emotional support) (Snyder & Pulvers, 2001; Tobin et al., 1989). In contrast, strategies focused on avoiding the stressor would be labelled *problem/ behavioural avoidance* (e.g., disengaging from attempts to resolve the stressor, withdrawing from others) and those focused on avoiding one's thoughts or emotions regarding the stressor would be labelled *emotion/cognitive avoidance* (e.g., disengaging from one's thoughts or feelings about the stressor, engaging in fantasy) (Snyder & Pulvers, 2001; Tobin et al., 1989).

These conceptualisations are consistent both with Snyder and Pulver's (2001) environment-directed or self-directed view of approach strategies and with Gross's (1998) conceptualisation of cognitive strategies serving an emotional regulation function. They are also consistent with Folkman and Moskowitz's (2004) conceptualisation of problem-focused strategies as serving to change the source of stress and, therefore, as non-emotional actions.

While the distinction is made in terminology, the theme of problem-focused/emotion-focused coping and approach/avoidance coping is essentially similar. Problem-focused or approach strategies try to address stress externally while emotion-focused coping and avoidance strategies are internalised processes which may not affect the actual reality of a stressful encounter (Lazarus & Folkman, 1984b; Monat & Lazarus, 1991; Snyder & Pulvers, 2001; Tobin et al., 1989).

Folkman and Lazarus (1980) described *good coping* as a situation where the best coping process for a given situation is selected. This entails the best fit between the requirements of the situation, what one does and one's individual needs. It also entails flexibility, with reappraisals enabling switching between coping strategies, particularly where a strategy has been unsuccessful in managing the stressful relationship (Folkman & Lazarus, 1980).

The variability in strategies used may be due to the complexity of stressful encounters, and it may take time for individuals to find a coping strategy which best suits a situation (Lazarus & Folkman, 1984b). This trial and error process allows the best strategy to be employed in each situation and may be more important than the relative efficacy of one strategy over another (Folkman et al., 1986).

A further distinction must be made between dynamic coping processes and intrinsic defence mechanisms (Cramer, 2000). While there may be some overlaps, there are also clear theoretical differences, which are discussed in section 2.1.5.

Coping mechanisms have been shown to be methods that individuals use for stress reduction. Where those coping processes employed by the individual are focused on solving the stressful problem, then they may well be productive and stress-reducing, however when they are focused on simply deflecting the personal impact of that stress, without reducing the stressor, then they may be problematic, ongoing and counterproductive. Emotion-focused coping therefore, has the potential to be pathological in certain circumstances, such as the acutely stressful situations brought on by unexpected critical events.

2.1.5 Defence Mechanisms

The term *defence mechanism* is a theoretical construct that describes a cognitive operation that occurs on an unconscious level (Cramer, 2000, 2006). The function of this process, which on the surface appears similar to emotion-focused coping, is to modify the conscious experience of thought or affect, to protect the individual from excessive anxiety, and to protect the integration of the self (Cramer, 2006).

The concept of defence mechanisms was first raised by Sigmund Freud (Freud, 1920, 1924) and developed further by his daughter, Anna Freud (Freud, 1936). More recent work by Cramer (2006) describes defences as “unconscious mental mechanisms which are directed against both external and internal pressures, especially those that threaten self-esteem or the integration of the self” (p. 7).

When experiencing stress, an individual may consciously try to reduce anxiety by ignoring the stressor, by focussing on something else, or by seeking assistance elsewhere. These and other conscious attempts to reduce stress are referred to as coping mechanisms, which are theoretically different to defence mechanisms (Cramer, 2006). While coping mechanisms are commonly thought of as dynamic reactions to situations, defences are generally conceptualised as dispositional and part of the individual’s enduring personality (Cramer, 2006). Coping strategies sometimes address stress and anxiety by acting directly on the problematic situation, whereas defences are focused on changing internal states rather than external reality (Cramer, 2006).

Cramer (2006) suggested that there are two fundamental differences between coping and defence mechanisms:

- defence mechanisms occur without conscious effort and without conscious awareness whereas coping mechanisms involve a conscious purposeful effort, and
- defence mechanisms occur without any conscious intentionality, whereas coping strategies are carried out with the intent of managing or solving a problematic situation (p. 8).

Defence mechanisms function primarily to ward off excessive anxiety or other disruptive negative effect, and secondly to restore a comfortable level of functioning (Cramer, 2006). Furthermore, Cramer (2006) suggested the use of defences protects the individual from the conscious experience of anxiety, although arousal on the physiological level continues.

When an individual experiences some increase in psychological stress, then both coping and defence mechanisms may be employed. In some cases these processes may be common strategies, or at least have some overlap, and the greater the level of stress, the greater the level of defensive intervention or active coping required (Cramer, 2006).

Table 1 provides a comparison between these two concepts.

Coping process	**Defence mechanism**	**Difference**
Conscious	Unconscious	Critical
Used intentionally	Non-intentional	Critical
Situationally determined	Dispositional	Not a critical difference; a matter of emphasis
Non-hierarchical	Hierarchical	Not a critical difference; a matter of emphasis
Associated with normality	Associated with pathology	No difference, when self-report and context are controlled

Table 1 – Coping Processes and Defensive Mechanisms
(Cramer, 2006)

Cramer (2006) created a taxonomy of defence mechanisms, some of which are common to coping mechanisms. These are outlined in Table 2.

Level	Defences included
High adaptive	Altruism, humour, sublimation, suppression
Mental inhibitions	Displacement, dissociation, intellectualisation, isolation, repression, undoing
Minor image-distorting	Devaluation, idealisation, omnipotence
Disavowal	Denial, projection, rationalisation
Major image-distorting	Autistic fantasy, projective identification, splitting
Action	Acting out, apathetic withdrawal, passive aggression
Defensive dysregulation	Projection (delusional), denial (psychotic), distortion (psychotic)

Table 2 - The Defensive Functioning Scale: Hierarchical Levels of Defence
Cramer (2006)

While the majority of these mechanisms are beyond the scope of this thesis, the defence mechanism of denial is directly applicable and is discussed further in section 2.5.

Defence mechanisms, while similar to coping mechanisms, are a more trait-based means of managing stress in individuals. They may be employed strategically and unknowingly, to ward off chronic stressors, or as a default means of dealing with stress in some individuals.

2.1.6 Anxiety

The words “stress” and “anxiety” have often been used virtually interchangeably by some theorists (Stokes & Kite, 1994). Others have endeavoured to argue whether anxiety constitutes a cause of stress, an effect of stress, or, perhaps, a form or manifestation of stress (Stokes & Kite, 1994).

Stokes & Kite (1994) suggested the fundamental difference between stress and anxiety is that while stress may be a reaction to an actual, present danger, anxiety is rather an anticipatory construct that occurs when an expectation of harm exists. Rachman (2004) described this anxiousness as *“*the tense, unsettling anticipation of a threatening but vague event; a feeling of uneasy suspense” (p. 10). Sigmund Freud categorised anxiety as both a psychological and physiological state, with arousal being the manifestation of the physiological state (Freud, 1924). This is further reflected in a succinct definition produced by Webster’s Dictionary, which describes anxiety as: *“*an abnormal and overwhelming sense of apprehension and fear often marked by physiological signs (as sweating, tension, and increased pulse)*”* (Merriam-Webster, 2012).

Work by Cattell and Scheier (1961) and Spielberger (1966) separated anxiety into two types of anxious states: state anxiety (referred to as A-State) and trait anxiety (referred to as A-Trait). This differentiation, derived from multivariate analyses of anxiety factors, is important in that it delineates anxiety into separate phenomena.

When chronic anxiousness exists as a personality trait then prominent defences against such a state often exist (Stokes & Kite, 1994). Spielberger (1966) suggested, however, that individuals with chronic A-Trait dispositions, rather than living in a permanent state of dread, are rather simply more prone to perceiving situations as threatening, with more frequent activations of their anxious state. A-Trait individuals are simply more prone to anxiety and find themselves with a frequent tendency to respond with A-State when under stress (Stokes & Kite, 1994).

State anxiety in contrast is a transitory, acute, anticipatory emotional reaction to a specific perceived threat (Cattell & Scheier, 1961; Spielberger, 1972). In a similar manner to a mild stress reaction, it involves the activation of the autonomic nervous system, with accompanying rises in blood pressure, heart rate and galvanic skin response (McEwen, 2007). This is generally accompanied by perceptions of negative effect such as tension, apprehension and nervousness (Stokes & Kite, 1994).

Research (e.g., Broadbent & Broadbent, 1988; Calvo & Castillo, 2001; Mogg, Bradley, & Hallowell, 1994; Williams, Watts, MacLeod, & Mathews, 1988) has also shown repeatedly that both Trait and State anxious individuals show a bias towards emotionally threatening stimuli. This has been underpinned by three theories: Beck’s (1976), which suggests that anxiety vulnerability relates to strong activation of schemas that are geared toward the processing of threat-related information; Bower’s (1981) network theory, which states that a given emotional state leads to an activation of memory representations that are mood congruent which in turn results in the selective processing of this information; and MacLeod and Matthews; theory (1988), which holds that such selective processing for threat-based cues occurs in high-trait anxious individuals under certain circumstances (possibly an interaction effect between trait and state anxiety).

One outcome from research into this bias towards emotionally threatening stimuli is that anxious subjects take more time to process threat-related information than non-anxious subjects (Stokes & Kite, 1994). Some investigations have discovered effects across both State and Trait anxiety conditions (e.g., MacLeod & Mathews, 1988; Skosnik, Chatterton, Swisher, & Park, 2000), while other research has shown interference effects predominantly in subjects high in

Trait anxiety (e.g., Mogg, Matthews, & Weinman, 1989; Mogg, Matthews, Bird, & Macgregor-Morris, 1990; Pury & Mineka, 2001). Interestingly, Fox (1993) found that under some circumstances state-anxious individuals actually shift their attention away from threat stimuli, suggesting that this was an attempt to use a repressive coping strategy.

MacLeod (1996) also suggested that anxiety creates reductions in cognitive performance by allocating mental resources away from the task at hand and towards task-irrelevant, threat-related information. This was confirmed in subsequent research (e.g., Wofford, 2001; Wofford & Goodwin, 2002; Wofford, Goodwin & Daly, 1999) which has found consistently improved performance under stress amongst low Trait anxious individuals compared to high Trait anxious individuals, across several domains. The effects of stress and anxiety on cognition are explored further below.

The terms anxiety and stress have been shown to overlap in some literature, however the predominant difference appears to lie in the anticipatory nature of anxiety, as opposed to the current nature of stress. Additionally, anxiety appears to be trait-based in some individuals. In these people, anxiety is an ongoing state, as opposed to a situational one, and their level of stress may be adversely affected, either chronically or acutely, as a result.

2.1.7 The Effects of Stress on Cognition

Several researchers have explored the relationship between anxiety/stress and cognition, with consistent results showing impaired information processing under the influence of stress (e.g., Bishop, 2009; Eysenck et al., 2007; Eysenck et al., 2005; MacLeod, 1996; Salthouse, 2012; Wickens & Hollands, 2000). MacLeod (1996) showed that decrements in anxiety-linked performance are closely linked to critical restrictions in the central cognitive system, rather than simply being due to attentional narrowing. While stress clearly restricts cue sampling and narrows the perceptive field (Combs & Taylor, 1952; Easterbrook, 1959), it has also been shown to decrease vigilance (Wachtel, 1968) and importantly, reduce the capacity of the working memory (Eysenck & Calvo, 1992; Lavric, Rippon, & Grey, 2003; Wickens et al., 1991). These effects have also been shown through experiments to divert attention to short-range issues at the expense of long-range ones (Smart & Vertinsky, 1977) and also to create some rigidity in problem-solving and decision-making tasks (Janis & Mann, 1977; Stow, Sanderlands, & Dutton, 1981; Yamamoto, 1984).

Anecdotal evidence of “cognitive tunnel vision”, where participants were unable to revise earlier perceptions of an event, have also been noted by Wickens (1984). Additionally, participants tended to show repeated resistance to events not specified in operating procedures (Gertman, Haney, Jenkins, & Blackman, 1985). This failure to think beyond prescribed procedures clearly reduces problem-solving capabilities where complex, multifaceted or ambiguous situations exist, requiring resolution. Problem-solving and decision-making are also affected through perseveration with a favoured option, indecision or hypervigilance, under stressful conditions (Kontogianis, 1996; Serpell, Waller, Fearon, & Meyer, 2009; Zakay, 1993).

This perseveration or inclination to continue with a given plan of action (which has possibly been used successfully in the past) has commonly led to inappropriate or ineffective strategies being used under stress. Experiments by Luchins (1942) for instance, found that under stress people were more likely to continue trying to use the same unsuccessful solution, even when that stress was heightened by the failure of the unsuccessful strategy. Other similar tests using threat of shock (Cowen, 1952) and heat, crowding and distraction (Shameau & Dino, 1993) showed similar decrements in diversity or creative thinking under stress.

Considerable research has been completed on the effects of stress on attentional narrowing (e.g., Bacon, 1974; Baddeley, 1972; Hockey, 1970). In one experiment, Weltman, Smith, and Egstrom (1971) compared the performance of two groups of subjects on a central and peripheral detection task. One group was (falsely) led to believe it was experiencing the conditions of a 60-foot (18.3-metre) dive in a pressure chamber, and the other was not. Results showed similar performance on the central task, but results were far worse on the peripheral task amongst the stressed group. Supporting this, Edland (1989) showed that stress-induced tunnelling was worse when the processing of relatively more information channels was necessary.

Both perseveration and attentional narrowing have been shown to contribute to a pattern of convergent thinking (cognitive narrowing or tunnelling), which can be dangerous during critical decision-making (Dehais, Tessier, Christophe, & Reuzeau, 2010; Gaba, 1992; Speier, Valacich, & Vessey, 2003; Tenenbaum, Yuval, Elbaz, Bar-Eli, & Weinburg, 1993; Woods et al., 1994). Stress has been shown to narrow the cues sampled and processed to only those which are deemed to be relevant and important. This may prevent a decision-maker from using other cues which could support an alternative hypothesis, or decision, and has been commonly noted in behaviours in incidents such as the Three Mile Island nuclear meltdown and numerous cases of inexperienced pilots continuing to fly into bad weather (Griffin & Rockwell, 1987; Jensen, 1982; Simmel, Cerkovnik, & McGarthy, 1987). The combined effects of attentional tunnelling and perseveration could have significant effects on the successful handling of an aircraft emergency (Woods et al., 1994) and accidents such as Ansett New Zealand Flight 703, United

Airlines Flight 173, and Eastern Airlines Flight 401 (in which attention was focused on a landing gear problem) are not atypical (NTSB, 1973, 1978;TAIC, 1995).

While clearly attentional narrowing has implications for peripheral but important information being neglected, research has shown that stress-produced perceptual tunnelling has actually improved performance under some circumstances. One such experiment by Houston (1969), using noise stress during completion of a coloured ink Stroop test, found that the presence of noise led to a greater focus on the relevant ink colour, leading to improved Stroop performance.

Houston's experiment, while suggesting that the stress effect on tunnelling is not simply a filtering of peripheral stimuli through narrowing of the attentional focus area, rather suggests that the filtering is influenced by the priority or importance of the peripheral stimuli (Matthews, Davies, Westerman, & Stammers, 2008). Bacon (1974) and Broadbent (1971) support this theory, suggesting that performance on those tasks of greatest subjective importance remain unaffected in their processing, or even enhanced (through arousal), whereas those of lower priority are filtered. This may seem to be adaptive and desirable; however, it can produce problematic consequences when the high subjective importance of the attended channel proves to be unwarranted. This was the case in the Three Mile Island Nuclear Power Plant incident, when highly stressed operators focused on the abnormally high water level indications, at the expense of other, more reliable indications which supported an opposite hypothesis (Staal, 2004).

The working memory has been shown by Baddeley (1986, 2000) to have four main components: a central executive, a visuospatial sketch pad, a phonological loop and an episodic buffer. Considerable research has been done into the effects of stress and anxiety on working memory function. Berkun (1964), Davies and Parasuraman (1982), Hockey (1986) and Wachtel (1968) have all identified the negative effects which stress or anxiety have on working memory capacity. Berkun (1964) and Stokes and Raby (1989) theorised that stressors can distract or divert attention from rehearsal of material that is either phonetic or spatial in a way that will allow the representation of that information to be degraded. One study by Wickens, Stokes, Barnett and Hyman (1989), involving flight simulator experiments on pilot decision-making tasks, showed that the effect of noise was quite pronounced on tasks requiring spatial visualisation for their successful resolution. Similarly, in a study of stress-related aircraft accidents by Orasanu (1997), reductions in situation awareness in stressful encounters was typical of working memory impairment.

The effects of stress on cognitive performance have generally been characterised in an inverted U relationship, represented commonly by the Yerkes Dodson Law (Yerkes & Dodson, 1908). The pattern of these effects (shown in Figure 3) shows degraded performance at lower levels of arousal (stress) and also at higher levels of arousal, with peak performance at moderate levels of arousal

Image removed

Figure 3: The generalised relationship between arousal and performance (commonly referred to as the Yerkes Dodson Law)

Figure 3 has been expanded to show the difference between performance under varying levels of arousal during both complex and simple tasks (Figure 4).

Image removed

Figure 4: Arousal and the effects of complexity on task performance

The reason for the mismatch between peak performance under stress on tasks of different complexity is assumed to occur because more complex tasks usually involve greater demands for attentional selectivity and more working memory load, and are therefore more susceptible to breakdowns of these processes at higher arousal levels (Staal, 2004).

Other stress research (e.g., Berkun, 1964; Flin, O'Connor, & Chrichton, 2008; Flin, Salas, Strub, & Martin, 1997; Stokes, Kemper, & Kite, 1997; Stokes & Kite, 1994; Wiggins, Stevens, Howard, Henley, & O'Hare, 1997) has shown that expert or highly skilled operators are generally more immune or "buffered" from the negative effects of stress than are novices. Studies by several researchers (e.g., Johnstone & Cannon-Bowers, 1996; Mandler, 1984; Meichenbaum, 1985) have shown that experience in stressful situations lowered the perceived level of stress in future events of the same nature, including anticipated anxiety for such events. Ursin, Baade and Levine (1978), for instance, showed substantial drops in stress levels between first and second parachute jumps, as participants felt empowered following successful completion of their first jump.

Keinan and Friedland (1996) suggested three principal reasons for this expertise effect. Firstly, skill leads to automaticity of tasks and to the replacement of knowledge-based behaviour by skill and rule-based behaviour. This leads to less resource requirement during multiple tasks and less likelihood of failure, which is in itself a source of considerable stress. One proviso of this concept, however, is that where such an expert encounters an unfamiliar situation, such as a novel emergency, then their well-trained and automated routines are no longer well suited and they are as susceptible to the effects of stress as novices. While expertise, therefore, may provide some inoculation against routine stressors, it is not sufficient to provide effective stress response to failure (Keinan & Friedland, 1996). A second improvement in performance amongst experts may be due to their larger repertoire of strategies available to deal with tasks. This also allows them to monitor and understand the effectiveness of those strategies and to be better able to adaptively shift between strategies when necessary. Finally, experts may better be aware of the performance effects of stress and have a larger range of coping strategies available for different stressors (Keinan & Friedland, 1996).

The effects of stress on cognition may be profound. Research has shown that attentional narrowing, affected vigilance, perseveration and working memory disruption are just some effects which can negatively impact on human performance under stress. During critical events, when situational awareness, problem-solving and decision-making may require excellent mental acuity for a successful outcome, performance may therefore be adversely affected by stress.

2.2 Cognition

2.2.1 The Human Information Processing System

The human processes for acquiring and processing information in the environment are both complex and fallible. Humans are susceptible to breakdowns in this process through several means, including attending to incorrect or unimportant information at the expense of more relevant stimuli, misperception of the data that have been attended to, breakdowns in processing information in working memory, and incorrect storage and recall of that information in long-term memory structures, particularly under the effects of stress and fatigue (Matthews et al., 2008; Wickens & Carswell, 1997; Wickens & Flach, 1988).

Several models of human information processing have been proposed in the research (e.g., by Atkinson & Shiffrin, 1968; Broadbent, 1958; Craik & Lockhart, 1972; Deutsch & Deutsch, 1963; Mayer, 2001; Rumelhart, & McClelland, 1986; Schnotz & Bannert, 2003; Treisman, 1964; Wickens & Hollands, 2000). One which is illustrative of common recent theory is that of Wickens (1992), which is outlined below in Figure 5.

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Figure 5 Wickens' Model of Human Information Processing
Adapted from Wickens (1992)

A succinct description of this model is provided by Matthews et al. (2008):

> In this model external stimuli are received through the five senses. From there initial perceptual processes transform the neural outputs of the senses into abstract codes representing objects and their attributes. The physical properties of these stimuli are preserved in short term sensory stores (STSS), where decay occurs very rapidly: iconic (visual) memories for instance may only persist for a few hundred milliseconds, while echoic (auditory) memories may last for a few seconds. Information from the STSS then undergoes more rigorous perception processes, where the stimulus is identified or categorised in terms of its personal significance. This requires some analysis of its semantic properties as well as physical attributes. Following this perceptual recognition process information is passed to decision and response selection processes in which an assessment of the implications for action are made, including choice of an overt response. Evaluation of the stimulus and its implications are memory based, guided by past experiences and knowledge represented in long term memory. Working memory may also be required for central processing as the person "thinks about" the stimulus. This "thinking" may involve internal computations which reveal further properties of the stimulus, or simply facilitate response selection. From here a response will eventually be selected, which is in turn executed by the appropriate muscles. This whole process is dynamic, as feedback signals provide on-going interaction with the external world. (p. 46)

Within the physical brain, this process commences with stimuli arriving at the various sensory organs. From there the stimuli are routed via various means to the thalamus, with the exception of olfactory stimuli, which are processed directly in the olfactory cortex. The thalamus then relays sensory information to the amygdala, which is a site of basic emotion memory, and to the cortex, where cognition occurs. From the cortex the stimuli are projected to the hippocampus, a site involved in memory and linked to the amygdala. Before a sensory perception has reached the frontal lobes (cortex), when it enters conscious awareness and undergoes fine categorisation, the amygdala has already branded it with raw emotional continuum from mildly interesting to not interesting at all (primary appraisal process). The amygdala provides a preconscious bias of integrity to every stimulus encountered. Because our neural emotional system can act independently of the neocortex, some emotional reactions and emotional memories can be formed without any conscious, cognitive participation at all. Indeed, given the time involved in cognitive processing (500ms+), emotional response (14ms+) can easily precede a cognitive perception and response (Åsli & Flaten, 2012; LeDoux, 1996; Lyons, 2000). Further discussion on the amygdala is provided later in this chapter.

2.2.2 Attention

Attention has been widely conceptualised in the research for a hundred years or more as an ability to concentrate on one or more stimuli (e.g., Allport, 1989; Broadbent, 1971; Duncan, 1996; James, 1890; Johnston & Dark, 1986; Schneider, 1995; Titchener, 1910; Pashler & Johnson, 1998; Van der Heidjen, 1992; Wickens & Holland, 1984). Lyons (2003) described the brain's attention system as one which:

- constantly surveys the environment to determine what is and is not important;
- decides how much and what kind of sensory information is needed to complete a task;
- allocates varied amounts of mental energy depending on task demands;
- sustains focus when the task is not interesting;
- determines if and when the task will be completed;
- persists in tasks long enough to finish them despite distractions; and
- disengages from a current task when something more important requires immediate attention, response or action. (p. 26)

Ratey (2002) described four distinct components within the attention system, which together create the brain's overall ability to monitor the environment: arousal, motor orientation, novelty detection and reward, and executive organisation. These are outlined in Table 3.

Component	Definition	Location of Brain Structures
Arousal	Ability to suddenly increase alertness	Reticulus Attention System
Motor Orientation	Facilitates and maintains arousal	Cerebellum
Novelty Detection & Reward	Focuses and sustains attention	Limbic system (includes portions of frontal and parietal lobes, hypothalamus, and pathways that connect them
Executive Organisation	Directs actions and integrates entire attention system	Prefrontal cortex and cingulate gyrus

Table 3 – Components of the Attention System
(Ratey, 2002)

Attention has further been broken down into three distinct types: selective attention, divided attention and sustained (or focused) attention (Matthews et al., 2008; Wickens & Holland, 2000).

Selective attention occurs when a person must respond to some stimuli, or stimulus properties, whilst ignoring others (Matthews et al., 2008). Divided attention occurs when a person must perform two or more tasks simultaneously. This may lead to performance breakdown (known as dual-task interference) (Matthews et al., 2008). Sustained (or focused) attention occurs when a person must sustain their focus of attention over a relatively long time period (Matthews et al., 2008). This is sometimes referred to as vigilance and has significant implications for safety in the aviation industry.

2.2.3 The Amygdala

It has been shown that at the heart of the stress or anxiety reaction is an appraisal of threat or harm (e.g., Lazarus 1966, Lazarus & Folkman, 1984). This appraisal of threat or harm can be interpreted as a fearful response, and considerable research has been done into the neurological and physiological effects of actual or perceived fear in humans and other mammals (e.g., Adolphs, Tranel, Damasio, & Damasio, 1995; Åsli, & Flaten, 2012; Cook, Davis, Hawk, Spence, & Gautier, 1992; Davis, 1984, 1992, 1997; Fanselow, 1994; Graym, 1988; Grillon, et al., 1991; Kalin, 1993; Kim & Fanselow, 1992; Lang et al., 2000; LeDoux, 1996a; Misslin, 2003; Morris, Ohman, & Dolan, 1999; Phillips & LeDoux, 1992; Whalen, 1998).

Central to the appraisal process are the two almond-shaped organs in the limbic region of the brain known collectively as the amygdala, the amygdaloid complex, or the amygdaloid body (Folkman et al., 1986; Skinner & Brewer, 2002; Whalen & Phelps, 2009; Zohar & Brandt, 2002). Both of these amygdaloid structures appear virtually identical, with one on each side of the brain, although research suggests the right amygdala is more involved in emotional processing of current stimuli (Angrilli et al., 1996; Morris, Öhman, & Dolan, 1999; Phillips et al., 2001).

The amygdaloid complex is widely connected to other areas of the brain and is therefore ideally situated to influence cognitive functions as a reaction to emotional stimuli in the environment (Adolphs et al., 1995; Anderson, 2007; Akirav & Maroun, 2007; Davis, 1984, 1992; Fanselow, 1994; LeDoux, 1992, 1994, 1996a, 1996b, 2000, 2006; Whalen & Phelps, 2009). Research suggests that a primary function of these bodies is the modulation of neural systems which underlie both cognitive and social behaviours as a response to emotional cues (Anderson & Phelps, 2000; Whalen, 1998). It consists of a heterogenous group of nuclei and cortical regions located in the medial temporal lobe, rostral to the hippocampal formation (Whalen & Phelps, 2009), and is illustrated in Figures 6 and 7.

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Figure 6 – The Amygdala
(Reprinted with permission from posit science).

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Figure 7 – The Amygdala (medial view)
(Reprinted with permission from posit science).

There is general agreement amongst researchers that the amygdaloid complex is subdivided into three groups of nuclei: the corticomedial group with the cortical and medial nuclei, the central nucleus, and the basolateral group with the accessory basal, basal, and lateral nuclei (Amaral et al., 1992; McDonald, 1992; de Olmos, 2004; Mai, Paxinos, & Vos, 2008; LeDoux, 2000, 2006; Nieuwenhuys, Voogd, & van Huijzen, 2008; Whalen & Phelps, 2009).

Figure 8 shows the relative positions of various significant nuclei in the amygdaloid complex.

Image removed

Figure 8 - Regions of the human Amygdala
(LeDoux, 2000)

Of particular note are the Lateral nuclei (LA), the Basolateral nuclei (B) and the Central nuclei (CE). Sensory information arrives via LA and B and is routed to motor nuclei and elements of the autonomic nervous system via CE.

The role of the amygdala in the processing of emotionally and particularly fearfully valent information has been studied by researchers over the last two to three decades (e.g., Adolphs et al., 1995; Anderson, 2007; Davis, 1992, 1997; Fanselow, 1994; LeDoux, 1992, 1996, 2000, 2006; McDonald, 1998; McGaugh, 2004; Phelps, 2006; Whalen & Phelps, 2009; Zald, 2003). Of most significance in this study is the extensive recent research which has focused on the role of the amygdala in fear conditioning, with numerous studies using rats, rabbits, primates and humans (e.g., Fanselow & LeDoux, 1999; Fendt & Fanselow, 1999; Hitchcock & Davis, 1986; LeDoux, 2000; McKernan & Shinnick-Gallagher, 1997; Maren, Aharonov, & Fanselow, 1997; McEchron, Bouwmeester, Tseng, Weiss, & Disterhoft, 1998; Phillips & LeDoux, 1992; Rogan, Staubli, & LeDoux, 1997). Pavlovian fear conditioning has enabled researchers to elicit and measure specific fear responses in the amygdala which are theorised to represent the normal response of humans and other mammals. While human research has generally been limited to either functional magnetic resonance imaging, lesion type studies, or post-mortem examinations, research using rats and other animals has allowed real-time manipulation and measurement in vivo (Anderson & Phelps, 2001; Angrilli et al., 1996; Fendt, Koch, & Schnitzler, 1994; Hitchcock & Davis, 1986; Kim & Jung, 2006; LaBar, Gatenby, Gore, & LeDoux, 2003; LeDoux & Phelps, 1998; Maren, Ahronov, & Fanselow, 1997; Shi & Davis, 1998) .

While fear conditioning is unrelated to the topic of this thesis, it has allowed researchers to understand in considerable detail how the amygdala, and its associated brain systems, work when exposed to conditions of anticipated, perceived, or actually fearful situations (Fanselow & LeDoux, 1999; Fendt & Fanselow, 1999; Hitchcock & Davis, 1986; LeDoux, 2000; McKernan & Shinnick-Gallagher, 1997; Maren, Aharonov, & Fanselow, 1997; McEchron et al., 1998; Phillips & LeDoux, 1992; Rogan, Staubli, & LeDoux, 1997). This has particular relevance for the concepts of stress and anxiety which have been discussed already, and the startle and freeze phenomena which are discussed later in this chapter.

Fear conditioning trials involving rats have been considered sufficiently representative of human responses to be studied widely (e.g., Campeau & Davis; Glick, Ross & Hough, 1982; Davis, 1984; Eaton, 1984; McEchron et al., 1998; Maren et al., 1997; Milad et al., 2006). Such trials have generally involved pairing an unconditioned stimulus, such as a generic tone (or a light), with a foot shock in a specifically designed cage (see Figure 9). It has consistently been shown that when rats receive an electrical foot shock (conditioned stimulus) in the presence of a loud auditory tone (unconditioned stimulus) they quickly learn an association between these two stimuli, such that even after as few as one or two such iterations of this association, fear responses will appear in future iterations, even when only the unconditioned (tone) stimulus is applied (Davis, 1989; Davis & Astrachan, 1978; Davis & File, 1984; LeDoux, 2000). These experiments have allowed researchers to reliably and consistently generate fear responses in the brain (without actually shocking animals continually) which has in turn allowed them to measure the brain circuitry activated and measure such things as startle response and reaction times.

Image removed

Figure 9 – Typical Apparatus Used for Startle and Fear Conditioning Experiments on Mice (George Mason University)

Experiments have given researchers considerable evidence on the path of signals from emotionally salient information through the brain and other bodily systems (e.g., Davis, 1984, 1989). Figure 10 shows the pathways mediating auditory fear conditioning in rats. These involve the convergence of the conditioned stimulus (CS) and unconditioned stimulus (US) pathways onto single cells in the LA from thalamic and cortical processing regions in the sensory systems that process the CS (auditory system) and US (somatosensory system). The LA then connects with the CE both directly and by way of other amygdala regions (not shown) (LeDoux 2006).

Image removed

Figure 10 – Neural Pathways Underlying Fear Conditioning
(Phelps & LeDoux, 2005)

While these experiments with rats have demonstrated both auditory- and somatic-induced fear effects, some researchers have demonstrated similar effects when a light is paired with the CS (e.g., Davis, 1992). A considerable number of experiments using humans have also been conducted, showing similar effects in a visual modality, generally using pictures of people in different emotional states, or slideshows interspersed with images with strong emotional valence (such as images of snakes, for example) (Breiter et al., 1996; Büchel, Morris, Dolan, & Friston, 1998; Cook, Davis, Hawk, Spence, & Gautier, 1992; Hamann, Ely, Grafton, & Kilts, 1999; Hamm & Vaitl, 1996; Hawk & Cook, 1997; Jansen & Frijda, 1994; Morris et al., 1996; Patrick, 1994; Otto, Cousens, & Herzog, 2004; Vrana, Spence, & Lang, 1988; Whalen & Phelps, 2009). Other experiments involving olfactory pathways have also been conducted (e.g., Otto et al., 2000; Paschall & Davis, 2002; Sevelinges, Gervais, Messaoudi, Granjon, & Mouly, 2004).

Sensory inputs to the amygdala have been shown to generally arrive at the LA via two different routes (Davis, 1984, 1992; LeDoux, 2000, 2006). First, information from the senses is routed via the sensory thalamus to the amygdala, where a rapid assessment of emotional valence is made (appraisal) (LeDoux, 2000; LeDoux, Cicchetti, Xagoraris, & Romanski 1990; LeDoux, Farb, & Ruggiero, 1990). Second, that sensory information is routed from the sensory thalamus via the sensory cortex where it undergoes cortical processing, and then proceeds to the amygdala for modification or reinforcement of the original emotional salient information (Davis, 1992; LeDoux et al., 1984; LeDoux, 1994, 2000, 2002). In this way, the amygdala is able to rapidly instigate changes in the autonomic nervous system which enable an individual to rapidly respond to danger, without the need for cortical processing (Ratey, 2002). The downside of this is that we frequently receive false alarms, where our senses detect something that the amygdala regards as possibly threatening (such as a long slender object in the grass which could be a snake), which in turn activates the sympathetic nervous system to energise our defences (with such things as increased heart rate and adrenaline), only to have the whole process quashed when the cortex and amygdala process what has been seen and decides it is only a harmless stick (Pessoa, Japee, Sturman, & Ungerleider, 2005; Soares, 2010; Toner & Gates, 1985). The cortex would in this case send more complete sensory information to the amygdala (via its direct axon connections) and the fight or flight response (which had been initiated perhaps half a second earlier) would then be tempered by the parasympathetic nervous system and the alarm reaction would die down (LeDoux, 1994, 2000; Misslin, 2003).

2.2.4 Bottom-Up Versus Top-Down Processing

Dense feedback connections between the amygdala nuclei and widespread regions in the sensory cortex (McDonald, 1988; Price, Russchen, & Amaral, 1987; Whalen & Phelps, 2009) allow both *bottom-up* and *top-down* sensory processing (Kinchla & Wolfe, 1979; Mechelli, Price, & Friston, 2004; Sarter, Givens, & Bruno, 2001). Bottom-up processing involves passive detection and processing of stimuli from the environment, while top-down processing involves directed processing of selected stimuli (Gilbert & Sigman, 2007; Kinchla & Wolfe, 1979; Matthews et al., 2000; Rummelhart, 1977; von Stein, Chiang, & Konig, 2000; Wickens & Hollands, 2000).

The differentiation between bottom-up and top-down processing is important when considering concepts such as attention and vigilance. In the aviation paradigm pilots are confronted with multiple sensory cues, under various levels of arousal, and with varying levels of importance and relevance. The ability to apply top-down processing based on expectancy, context or objectives and goals, may influence whether important and perhaps critical information is attended to, either in a timely manner, or at all (Alexander, Stelzer, Kim, & Kaber, 2008; Endsley, 2001). Certainly at low levels of arousal, such as in the cruise in the middle of a long-haul flight when workload is very low, the presence of task-relevant top-down processing is probably minimal, while during an organised and controlled instrument approach, a pilot would generally be directing their attentional processing in a well-orchestrated, top-down manner through a routine of deliberate scans of instrumentation, completion of checklists, communication with other crewmembers or other agencies, scanning for external references and various other tasks which comprise the task load of the modern pilot (Endsley, 2013).

When considering an unexpected critical event, such as those experienced by the pilots aboard Qantas Flight 32 (ATSB, 2010) or Air France Flight 447 (BEA, 2012) for instance, the pilots involved were suddenly and unexpectedly confronted with overwhelming, confusing, ambiguous and even conflicting information in a life-threatening context. These pilots would have been confronted with overwhelming external sensory data in a largely bottom-up manner, all the while under the elevated arousal state brought on by a stressful emergency. Attempts to regain top-down control would have been swamped by continual incoming external stimuli which would be processed in a bottom-up fashion.

The major difference in these two examples was in their outcome: on the Qantas flight deck the experienced captain immediately pressed the altitude hold button which attenuated a lot of the adverse thrust effects and allowed immediate control of flight path; whereas on the Air France flight deck, the inexperienced first officer, exhibiting strong indications of startle, immediately pulled up, exacerbating the (perfectly survivable) flight control problem (BEA, 2012). The subsequent differences in immediate workload allowed the QF32 crew to make a considered analysis and work through the problem, while the AF447 crew continued to deal reactively with the ambiguous environmental cues in an uncontrolled and uncoordinated manner.

2.2.5 Sensory Processing in the Amygdala and Other Brain Systems

The cortical processing of incoming stimuli and the role of the amygdala in this process warrant further attention. The following section will examine the relationship between the amygdala and other brain subsystems, including those of the amygdala and the frontal cortex. It will be followed by an analysis of the inputs to and the outputs from the amygdala, which in turn mobilise bodily processes such as activation of the autonomic nervous system.

Figure 11 illustrates some of these important connections to various subsystems in the brain and their relative functions. Of note is the fact that connections to the striatum and bed nucleus of the stria terminalis are one-way, whereas all other connections are two-way:

Image removed

Figure 11 – Subcortical Connectivity of the Amygdala
(Adapted from Whalen & Phelps, 2009)

The amygdala is connected to the cortical areas in multiple ways. These will be examined separately.

2.2.6 Amygdala – Neocortex Connections

2.2.6.1 Frontal Cortex

The amygdala is heavily interconnected with the mediodorsal and orbital prefrontal cortices. These areas provide important social cues to the amygdala and in turn receive information to provide an emotional influence over social behaviour (Akirav & Maroun, 2007; Rolls, 2008; Whalen & Phelps, 2009).

2.2.6.2 Insular Cortex

The insular cortex provides one of the strongest cortical inputs to the amygdaloid complex, projecting to almost all of the amygdala nuclei. In turn, the amygdala projects throughout the insular cortex, which has been implicated in the mediation of heart rate and in taste and gustatory processing (Whalen & Phelps, 2009).

2.2.6.3 Cingulate Cortex

A moderate number of projections proceed from the rostral cingulate cortex, primarily into the LA and B nuclei of the amygdala (Pillay, Gruber, Rogowska, Simpson, & Yurgelun-Todd, 2006).

2.2.6.4 Temporal Cortex

The amygdala receives and projects extensive connections to and from the temporal cortical areas (Klinger & Gloor, 2004).

2.2.6.5 Occipital Cortex

While there appear to be no projections directly from the occipital cortices to the amygdala, there is evidence of the amygdala's BA nuclei projecting back to the occipital cortex, maintaining significant connections with different levels of the visual cortical areas (Whalen & Phelps, 2009).

2.2.7 Contextual Fear Conditioning

In addition to expressing fear responses to the CS, rats also exhibit fear responses simply when returned to the chamber in which the tone and shock have been previously paired, or a chamber in which shocks occurred alone. This is called contextual fear conditioning and has been shown to require inputs from both the amygdala and the hippocampus (Blanchard, Blanchard, & Fial, 1970; Frankland, Cestari, Filipkowski, McDonald, & Silva, 1998; Kim & Fanselow, 1992; McEchron, Bouwmeester, Tseng, Weiss, & Disterhoft, 1998; Maren, Aharenov, & Fanselow, 1997; Phillips & LeDoux 1992; Yaniv, Desmedt, Jaffard, & Richter-Levin, 2003).

In contextual conditioning experiments, areas of the ventral hippocampus (CA1 and subiculum) project to the basal (B) and accessory basal (AB) nuclei of the amygdala (Canteras & Swanson 1992). Figure 12 below illustrates this relationship.

Image removed

Figure 12 – Contextual fear conditioning neural pathways
(Phelps & LeDoux, 2005)

Contextual fear or sense of threat is a reality for some pilots when in flight simulators; the mere sight of a simulator can make some people exhibit signs of anxiety (Wilson, 2002). Similarly, a lot of people who suffer from apprehension about flying in general often exhibit feelings of strong anxiety simply being in an airport (Deran & Whitaker, 1980; van Gerwen, Spinhoven, & Diekstra, 1997; Wiederhold, Gervirtz, & Wiederhold, 1998).

2.2.8 Outputs from the Amygdala

While the pathways into the amygdala have been discussed, the outputs from the amygdala are of more importance to this thesis. Regardless of whether the appraisal of threat is received by direct stimulus through some sensory pathway, or via a contextual perception of fear/threat, all outputs from the amygdala proceed from the central nucleus (CE). From CE signals are transmitted to different brain and nervous system parts, including the lateral hypothalamus (LH), nucleus of the reticularus pontis caudalis (RPC), periacqueductal central grey (PAG), paraventricula nucleus (PVN), parabrachial nucleus and the ventral segmental area (Ulrich-Lai, 2009). These are further discussed below.

Lateral Hypothalamus (LH)

The lateral hypothalamus contains several substructures with distinctive nuclei. The hypothalamus controls the activation of the autonomic nervous system, initiating most physical manifestations of fear, such as a pounding heart, elevated blood pressure, paleness, sweating, dry mouth, pupil dilation and galvanic skin response (Davis, 1992; Kalat, 2001; LeDoux, 2000; Marieb, 1995; Martini, 2005).

The Nucleus of the Reticulus Pontis Caudalis (RPC)

The startle reflex, which is an involuntary, aversive and attentional orienting mechanism, is initiated by the amygdala and is then projected through the RPC. While people are startled all the time by unexpected events, experiments have shown a strong correlation between fear and potentiation of the startle response (Davis 1989, 1997; Davis et al., 1987; Fendt et al., 1994). The startle reflex is discussed further, later in this chapter.

Periacqueductal Central Grey (PAG)

The periaqueductal central grey (PAG) is a large structure in the midbrain which receives projections from the amygdala, and is associated with a pattern of defensive action in which ongoing behaviour is completely halted (except for breathing), resulting in a frozen or immobile posture (Benarroch, 2012; Carrive, 1993; Coombes, 2006; Davis, 1992; De Oca et al., 1998; LeDoux, 2000).

Paraventricular Nucleus (PVN)

Signals from the amygdala project directly to the PVN and activate the hypothalamic–pituitary–adrenocortical (HPA) axis (Herman & Cullinan, 1997). Stress activates hypophysiotrophic neurons in the paraventricular nucleus of the hypothalamus that secrete releasing hormones, such as corticotropin-releasing hormone (CRH) and arginine vasopressin (AVP), into the portal circulation of the median eminence. These releasing hormones act on the anterior pituitary to promote the secretion of ACTH, which in turn acts on the inner adrenal cortex to initiate the synthesis and release of glucocorticoid hormones such as cortisol in humans. Circulating glucocorticoids then promote the mobilisation of stored energy and potentiate numerous sympathetically mediated effects, such as peripheral vasoconstriction (Ulrich-Lai & Herman, 2009).

Parabrachial Nucleus

Information received in the parabrachial nucleus stimulates increased respiration, which can result in panting or even respiratory distress (Fox, 1993; Martini, 2005).

Ventral Tegmental Area

Signals received in locus coeruleus nuclei, dorsal lateral tegmental nuclei and nuclei in the ventral tegmental area of the hindbrain stimulate secretion of hormones such as dopamine, norepinephrine and acetylcholine which increase behavioural and EEG arousal, and vigilance processes (Fox, 1993; Martini, 2005; Snyder, Wang, Han, McFadden & Valentino, 2012).

Figure 13 illustrates the pathways from the amygdala.

Image removed

Figure 13 – Output from the amygdala in the human stress response
Modified from Davis (1992)

The amygdala has wide connectivity with both body and brain structures and appears to be critical in the evaluative processes of fear and threat. It is also widely involved in initiating emotional responses and endocrinal changes in the body to cope with perceived threat.

2.2.9 The Hypothalamic-Pituitary-Adrenocortical Axis (HPA)

The HPA axis is one of the most important elements in the manifestation of the stress response (Carrasco & Van de Kar, 2003). As the name suggests, it describes the relationship between the hypothalamus, the anterior pituitary gland and the adrenal system (Carrasco & Van de Kar, 2003; Charmandari, Tsigos, & Chrousos, 2005; Chrousos, 1992; Ellis, Jackson, & Boyce, 2006; Herman & Cullinan, 1997; Johnson, Kamilaris, Chrousos, & Gold 1992; McEwen, 2007; Papadimitriou & Piftis, 2009; Stratakis & Chrousos, 1995; Tsigos & Chrousos, 2002; Ulrich-Lai & Herman, 1995; Vermetten & Bremner, 2002a, 2002b). Figure 14 illustrates this overall relationship.

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Figure 14 – The HPA axis
(http://www.montana.edu/wwwai/imsd/alcohol/Vanessa/vwhpa.htm)

An expanded view of the hypothalamus/pituitary section, including sections involved in hormone activity in the HPA axis, is shown in Figure 15.

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Figure 15 – Expanded view of the Hypothalamic-Pituitary section of the HPA axis (Boron & Boulpaep, 2009)

The hypothalamus is stimulated by its inputs and then proceeds to secrete CRH (Charmandari et al., 2005; Chrousos, 1992; Ellis et al., 2006; Papadimitriou & Piftis, 2009). This hormone is transported to its target, the pituitary gland, via the hypophyseal portal system (Papadimitriou & Piftis, 2009), to which it binds and causes the pituitary gland to, in turn, secrete its own messenger, ACTH, systemically into the bloodstream (Stratakis & Chrousos, 1995; Tsigos & Chrousos, 2002). When ACTH reaches the adrenal gland, it releases another hormone, cortisol (Ellis et al., 2006; Tsigos & Chrousos, 2002). Cortisol has widespread effects in the body. During an alarming situation in which a threat is detected and signalled to the hypothalamus from primary sensory and limbic structures, the brain uses cortisol to instruct the body to attempt to regain homeostasis – by redistributing energy (glucocorticoids) to areas of the body that need it most, that is, toward critical organs (such as the heart and the brain) and away from digestive and reproductive organs (Ellis et al., 2006; Sapolsky, Krey, & McEwen, 1986; Tsigos & Chrousos, 2002).

After enough cortisol has been secreted to best restore homeostasis and the body's stressor is no longer present or the threat is no longer perceived, the heightened levels of cortisol in the body's bloodstream eventually circulate to the pituitary gland and hypothalamus to which cortisol can bind with glucocorticoid receptors (Peterset al., 2007; Sapolsky et al., 1984) and inhibit the HPA-axis' stress-response cascade via feedback inhibition, preventing additional cortisol from being released. This is biologically identified as a normal, healthy stress mechanism in response to a situation or stressor – a biological coping mechanism for a threat to homeostasis (Myers & Davis, 2007; Peters et al., 2007; Tsigos & Chrousos, 2002).

2.2.10 The Human Nervous System

The nervous system is a complex network that receives sensory data from inside and outside the body. It is primarily concerned with the processing of sensory input or with the execution of motor output (physical action) (Best, nd). It responds to changes and demands, initiates and executes movements, and maintains the body's homeostasis. The nervous system can be divided into two: the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of the brain and the spinal cord, while the PNS is made up of the somatic nervous system and the autonomic nervous system (Berne & Levy, 1990; Fox, 1993; Kalat, 2001; Marieb, 1995; Martini, 2005). These are further divided into the sympathetic nervous system and the parasympathetic nervous system (PSNS) (Berne & Levy, 1990; Fox, 1993; Kalat, 2001; Marieb, 1995; Martini, 2005), which are discussed further below.

Figure 16 shows the principal components of the nervous system and their functional structure.

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Figure 16 – Structure of the Human Nervous System
(Serendip Studio, 2013)

2.2.10.1 The Autonomic Nervous System

The autonomic nervous system is that branch of the CNS which acts in an unconscious, predominantly automatic and self-regulated manner to activate the body's systems in response to a stressor or to restore the body to a state of homeostasis (Berne & Levy, 1990; Fox, 1993; Kalat, 2001; Marieb, 1995; Martini, 2005). It is further divided into three separate systems: the SNS, which activates arousal mechanisms, the PSNS, which acts to dampen the arousal state and restore homeostasis, and the enteric system, which controls the various workings of the gut (Berne & Levy, 1990; Goyal & Hirano, 1996).

2.2.10.2 The Sympathetic Nervous System

The sympathetic division of the autonomic nervous system provides a rapidly responding mechanism that controls the acute response of an organism to a stressor. It widely innervates vascular smooth muscle cells, as well as the kidney, gut, and many other organs, and the adrenal medulla (Fox, 1993). In addition to acetylcholine, norepinephrine, and epinephrine, both the sympathetic and the parasympathetic divisions of the autonomic nervous system secrete a variety of neuropeptides, such as neuropeptide Y somatostatin, galanin, enkephalin, and neurotensin, as well as adenosine triphosphate and nitric oxide (Charmandari et al., 2005; Fox, 1993; Johnson et al., 1992; Tsigos & Chrousos, 2002). The particular combination of these substances in the neurons of the ANS during the stress response is strongly affected by the CNS and the interaction with the HPA axis. Circulating ACTH is the key regulator of glucocorticoid secretion by the adrenal cortex, but other hormones, some of them originating in the adrenal medulla, participate as well (Charmandari et al., 2005; Johnson et al., 1992; Tsigos & Chrousos, 2002). Glucocorticoids are the final effectors of the HPA axis and participate in the control of whole body homeostasis and the organism's response to stress. They also play a key regulatory role in the basal activity of the HPA axis and in the termination of the stress response by exerting negative feedback on the CNS components of the stress system (Charmandari et al., 2005; Sapolsky et al., 1995; Stratakis & Chrousos, 2006).

Figure 17 illustrates the relationship between the HPA, the SNS and elements of the PNS.

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Figure 17 – The Relationship Between the HPA, the Sympathetic Nervous System and Elements of the Parasympathetic Nervous System
(Ulrich-Lai & Herman, 2009)

The sympatho-adrenomedullary (left side) and HPA (right side) axes are the primary systems for maintaining or reinstating homeostasis during stress (Carrasco & Van de Kar, 2003; Charmandari et al., 2005; Chrousos, 1992; Ellis, Jackson, & Boyce, 2006; Herman & Cullinan, 1997; Johnson et al., 1992; McEwen, 2007; Papadimitriou & Piftis, 2009; Stratakis & Chrousos, 1995; Tsigos & Chrousos, 2002; Ulrich-Lai & Herman, 1995; Vermetten & Bremner, 2002a, 2002b). Stressor exposure results in activation of preganglionic sympathetic neurons in the intermediolateral cell column of the thoracolumbar spinal cord (shown in blue) (Berne & Levy, 1990; Fox, 1993). These preganglionic neurons project to pre- or paravertebral ganglia that in turn project to end organs and to chromaffin cells of the adrenal medulla. This sympathetic activation represents the classic fight or flight response (Fox, 1993; Marieb, 1995; Martini, 2005).

2.2.10.3 The Parasympathetic Nervous System

While the SNS is responsible for activating the arousal systems of the body, to prepare for danger and to be ready to act (Fox, 1993; Marieb, 1995; Martini, 2005), the parasympathetic branch of the ANS is constantly working in opposition (Martini, 2005). It is continually trying to return the body to a state of homeostasis, to the natural arousal levels persevering in pre-stressed states (Charmandari et al., 2005; Sapolsky et al., 1995; Stratakis & Chrousos, 2006). Figure 18 shows those elements affected by the parasympathetic arm of the ANS.

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Figure 18 – Elements in the Parasympathetic Nervous System
(http://faculty.ccri.edu/kamontgomery/pharmacology_of_the_nervous_syst.htm)

The following activities occur when the PSNS is commanded to counteract the increased arousal state imposed by the SNS:

- pupillary constriction,
- constrictions by the digestive glands,
- increased smooth muscle activity along the gastrointestinal tract,
- constriction in the bronchial system,
- reduced heart rat,
- negative inotropic effects (which decrease heart muscle contraction strength), and
- contractions in the bladder and genital constriction (Johnson, nd; Martini, 2005).

All of these functions work in opposition to the sympathetic arm of the ANS.

Both the sympathetic and parasympathetic arms of the nervous system have critical roles in activation of our bodies for meeting threats, and in maintaining, or returning our body, to a state of homeostasis. They are perpetually counteracting each other and usually do so with very good effect.

2.2.11 Memory Systems

Earlier discussion on information processing identified the three types of memory: short term sensory memory (which may only last 0.5-3 seconds) (Wickens, 1992), working memory (WM) which may last for around 20 seconds (Baddeley, 1986, 2000), and long-term memory (LTM), where memories are stored permanently (Collins, Gathercole, Conway, & Morris, 1993). Considerable debate still exists over the exact relationship between these memory systems, which are well researched and documented, and the concept of *emotional memory* (Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Hamann, 2001; LaBar & Cabeza, 2006; LeDoux, 1993, 2006). Discussion on memory systems (particularly WM and LTM) and their relationship with the emotional memory, which is both learned during emotionally valent encounters, and used in the appraisal of emotionally significant encounters, continues (e.g., Dolcos, LaBar & Cabeza, 2004; LaBar & Cabeza, 2006; LeDoux, 2006)

2.2.11.1 Working Memory

Working memory (sometimes referred to as “short term memory” in some older literature, e.g., Baddeley, 1966), has been studied extensively (e.g., Baddeley, 1986; Baddeley & Hitch, 1974, 2010; Brown, Hulme, & Dalloz, 1996; Cowan, 1988, 1995; Jones, 1993; Jones, Farrand, Stuart,

& Morris, 1995; Logie, 1995; Norman & Shallice, 1986; Reisberg, 1997). The conceptualisation of this memory type falls largely into three different categories: activation models, blackboard models and multi-store models (Matthews et al., 2008).

Activation models work on the assumption that STM is simply the activated portions of LTM (Matthews et al., 2008). Cowan (1988, 1995) a supporter of this theory, suggested that activation in this model does not necessarily imply conscious recognition (which requires focused attention), but rather that a subset of activated LTM items are kept within the focus of attention, requiring both top-down and bottom-up processing. In this situation novel stimuli attract attention automatically, however, a central executive system exerts voluntary top down control over both the focus of attention and controlled actions (Cowan, 1988, 1995; Matthews et al., 2000).

Blackboard models, by contrast, suggest that processing is controlled by independent modules that send information to a central "blackboard" which registers processing outputs. In this model, STM is simply the content of the blackboard which is overwritten or decays with time (Jones, 1993; Matthews et al., 2008).

The most commonly cited concept of WM is that devised by Baddeley (1986). In his model, which was updated in 2000 (Baddeley, 2000, Figure 32 below), a variety of different stores perform different functions. Top-down control of processing is implemented by the central executive, which was initially thought to perform several tasks including controlling short-term retention of information from the early stages of processing (Baddeley, 1986; Norman & Shallice, 1986). More recent work, however, suggests that the central executive is a purely attentional system whose role extends beyond memory function (Baddeley, 1996; Baddeley & Hitch, 2010; Baddeley & Logie, 1999). In addition to the control element are two slave systems: the phonological loop, which holds information as a code in phonological store, and the visio-spatial sketchpad, which is used for storage of geometric images (Baddeley, 1986, 2000; Collins et al., 1993; Logie, 1995; Matthews et al., 2008). An additional element, the episodic buffer, was added in 2000 (Baddeley, 2000). The episodic buffer is assumed to represent a storage system using a multimodal code. It is assumed to be episodic in the sense that it holds integrated episodes or scenes and to be a buffer in providing a limited capacity interface between systems using different codes (Baddeley, 2000). The episodic buffer is assumed to be capable of combining information from LTM with that from the slave systems. (Baddeley, 2000; Cowan, 2005). Figure 19 shows this relationship.

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Figure 19 – Baddeley's updated model of working memory
(Baddeley, 2000)

Working memory, where the processing of relevant information occurs, is particularly important in problem-solving and decision-making, and appears to be susceptible to breakdowns during stress and anxiety. It is also affected by limitations on capacity, which may vary from person to person, or in any given person in varying situations. Reductions in WM capacity or function are likely to have a negative impact on the speed and accuracy of problem resolution and action planning during critical events.

2.2.11.2 Long Term Memory

Long term memory is made up of two major types: explicit memory and implicit memory (Collins et al., 1993; Matthews et al., 2008, Squire, 2004; Stanford, 2006). Explicit memories are those memories that we can consciously remember, whereas implicit memories are those memories that we do not consciously remember.

Explicit memory (also known as declarative memory) involves both semantic and episodic memory (Collins et al., 1993; Matthews et al., 2008; Squire, 2004). Semantic memory is the memory we have about words and concepts, their properties, and interrelations (Tulving, 1972), whereas episodic memory is a database we have stored for personal, autobiographical type memories (Collins et al., 1993). Episodic memory is useful for allowing us to recall a specific event, whereas declarative memory allows us to recall facts and figures and was defined by Tulving (1972) as “the conscious knowledge of temporally dated, spatially located, and personally experienced events or episodes” (p. 386).

Implicit memory, which is also referred to as non-declarative memory, is more procedural in nature but also includes associative learning, non-associative learning and priming (Collins et al., 1993; Matthews et al., 2008). It refers to non-conscious forms of long-term memory that are expressed as a change in behaviour without any conscious recollection (Stanford, 2006).

Figure 20 shows the relationship between the elements in long term memory and also shows the areas of the brain associated with those functions.

Image removed

Figure 20 – The structure of long term memory
Adapted from Kandel, Kupferman, & Iverson (2000)

The effective storage and recall of critical information may have some impact on our ability to deal with critical events. Recall of emergency procedures or of correct responses to unexpected aircraft states may be impaired by startle, by stress, or through incorrect interpretation of environmental cues. By not recalling correct procedures at an appropriate time, the possibility exists for undesired aircraft states to develop or to be exacerbated.

2.2.11.3 Emotional Memory

Considerable research has been done into emotional memory (e.g., Buchanan & Adolphs, 2002; Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Christianson, 1992; Christianson & Loftus, 1987; Hamann, 2001; Kensinger, 2004; LaBar & Cabeza, 2006; LeDoux, 1993, 2006, 1996, 2000; Phelps, 2004; Whalen & Phelps, 2009). A lot of this has focused on Pavlovian fear conditioning in rats and primates, but it has given some insight into the structure and processes of emotional memory in the human brain which shares a lot of similarities with these other species (Poldrack & Packard, 2003; Squire, 2004). At the heart of this research is the amygdala and its role in storing or facilitating emotionally affective memories (Hamann, 2001; LaBar & Cabeza, 2006; LeDoux, 1993, 2006; Markowitsch & McGaugh, 1995).

Current thinking suggests that associative memory traces are stored within the amygdala, while the amygdala tends to modulate the encoding of memory traces in the hippocampus and other related structures for declarative emotional memory (McGaugh, 2000, 2002, 2004; McGaugh et al., 1993; Packard et al., 1994). When an emotionally valent event is experienced, there are simultaneous and independent memory changes in these two parallel systems, with both systems combining to affect future behaviour (McGaugh, 2000, 2002, 2004). Figure 21 indicates some of the systems associated with emotional memory.

Image removed

Figure 21 – Potential mechanisms by which the amygdala mediates the influence of emotional arousal on memory.
(LaBar & Cabeza, 2006)

The non-declarative system assists in the formation of new emotionally valent associations and also in the initiation of rapid affective responses to emotional stimuli (Hamann, 2001; LaBar & Cabeza, 2006; LeDoux, 1993, 2006; Markowitsch & McGaugh, 1995; McGaugh, 2000, 2002, 2004; McGaugh et al., 1993; Packard et al., 1994). However, the amygdala-based non-declarative system lacks the specialised structures of the hippocampus and its adjacent structures in the parahippocampal region that support representations of emotional events in declarative memory, and other associated systems such as the striatum where skill and habit-based learning occurs (Anderson & Phelps, 2001; Dolan, 2002).

The amygdala is strongly implicated in the storage of memories with emotional valence and the recall of these memories in extremely rapid appraisals of new information for purposes of pattern matching. When new sensory cues are received and are matched against stored memories of negative affect, the amygdala has the ability to initiate bodily processes which would deal with this perceived threat.

2.3 Startle

2.3.1 The Startle Reaction

The startle reaction is the physical and mental response to a sudden unexpected stimulus. It is common to mammals, reptiles, birds, and amphibians (Simons, 1996). The reaction can be initiated by a trigger in any sensory modality (Simons & Zelson, 1985), but in the laboratory and in life in general it is commonly elicited through auditory (acoustic), tactile (somatosensory), or visual stimuli. It is an easily measurable phenomenon and extensive laboratory research has been conducted, as far back as the 1930s, often using acoustic apparatus such as starters' pistols or loud buzzers, or visual stimuli such as shocking pictures, generally embedded in slideshows or picture shows (Landis & Hunt, 1939; Davis, 1984, 1992; Grillon et al., 1991; Lang et al., 1990). Measurement of startle has largely involved high-speed photography, skin conductance resistance data, heart rate monitoring, and specially designed cages which measure startle amplitude in rat and mice experiments.

While considerable research has been done into the startle reflex using rats, primates, cats and other animals, much research (e.g., Bradley, Lang, & Cuthbert, 1993; Braff et al., 1978; Braff, Grillon, & Geyer, 1992; Cook, Davis, Hawk, Spence, & Gautier 1992; Davis & Heninger, 1972; Fillon, Dawson & Schell, 1993; Graham, 1975; Grillon et al., 1991; Landis & Hunt, 1939; Ornitz, Guthrie, Kaplan, Lane, & Norman, 1986; Lang et al., 1990; Lipp, Sheridan, & Siddle, 1994) has also proven to generalise to humans.

The distinction needs to be made very clear here regarding the difference between the startle *reflex*, which like other reflex actions in the body is a completely involuntary series of physical movements, and the startle or surprise *reaction*, which is akin to a stress response (commonly referred to as the fight or flight response) (Bracha et al., 2004; Canon, 1929; Fox, 1993; Marieb, 1995; Martini, 2005; McEwen, 2007),and involves the activation of the SNS and other bodily processes. While some early research looked solely at the startle reflex (e.g., Landis & Hunt, 1939), more recent studies have tended to focus on the associated arousal circuits activated, and a phenomenon known as *fear-potentiated startle*. These latter tests have shown that when a startle is induced in such a way that there is some element of fear associated with the stimulus and the subject under trial, then the strength and duration of the startle are increased, and are generally accompanied by the physiological arousal through the HPA and SNS discussed earlier (Bradley, Moulder, & Lang, 2005; Davis, 1989; Grillon et al., 1991; Grillon & Davis, 1995; Hamm et al., 1993; LeDoux, 2000; Misslin, 2003; Selye, 1956).

While the distinction between reflex and reaction seems straight forward, it must be pointed out that the startle reflex, which comes about as the result of some surprising stimulus, generally involves some activation of fear circuits in the brain, however false alarms have only a momentary effect. As a startling stimuli is appraised by the amygdala as emotionally valent and/or arousing, it will initiate the startle reflex through projections to the RPC (Davis 1989, 1997; Davis et al., 1987; Fendt et al., 1994), while parallel projections to the paraventricular nuclei in the hypothalamus also initiate the stress response via the HPA axis (Herman & Cullinan, 1997; Ulrich-Lai & Herman, 2009). When the stimulus proves to be of no significance, cortical processing, particularly in the medial pre-frontal cortex (LeDoux, 2000; Morgan, Romanski, & LeDoux, 1993; Sotres-Bayon, Cain, & LeDoux, 2006) which occurs after several hundred milliseconds (Åsli & Flaten, 2012; Davis, 1992), tells the recipient that this is a false alarm, and further activation of emotional distress circuits is inhibited (a process generally known as fear extinction) (Akirav & Maroun, 2007; Delgado, Nearing, LeDoux, & Phelps, 2008; LeDoux, 2000; 2003; Myers & Davis, 2007; Quirk & Gehlert, 2003; Quirk, Gonzalez-Lima, & Garcia, 2006; Radley, Gosselink, & Sawchenko, 2009; Sapolsky et al., 1984; Sotres-Bayon, Cain, & LeDoux, 2006). As a result the recipient's cognitive, emotional and endocrinal systems rapidly return to a state of pre-stimulus homeostasis with little disruption. It is therefore important to distinguish between a simple reflex action which dissipates very quickly (0.5–1.5 seconds generally), and the significant activation of other arousal circuits which may have lasting effects for up to 30 seconds or beyond (Thackray, 1988).

The simple startle reflex generally includes the following aversive actions:

- eye blink;
- forward movement of the head;
- a characteristic facial expression;
- raising of shoulders and moving them forward;
- motion of the upper arms away from the body;
- bending of the elbows so as to raise the forearms and hands;
- rotation of the forearms inwards so that the palms face each other;
- clenching of the fingers;
- motion of the upper body forward from the hips;
- tightening of the abdominal muscles;
- bending of the knees; and
- an orienting of the attentional system, which may involve rotating the head towards the stimulus (Simons, 1996, p. 9).

The onset of the startle reflex is very quick, with some experiments showing that onset always commences within 100ms (Ekman et al., 1985; Landis & Hunt, 1939). Other experiments have shown evidence of startle in facial muscles in as little as 14ms in humans (Davis, 1992). Yeomans and Frankland (1996) have further shown that information reaches the pons within 3 to 8 ms after a loud noise, and the full startle reflex occurs within 200ms.

2.3.2 Variations in Startle Intensity

Considerable research has been done into variations in startle intensity. Research has shown that the vigour and intensity of the startle varies systematically with an organism's emotional state (Haerich, 1994; Lang et al., 1990). The sensitivity of the startle depends on such factors as how loud, unexpected, terrifying, or improbable the stimulus is (Dilich, Kopernik, & Goebelbecker, 2002; Simons, 1996) and how dark, frightening, or dangerous the setting (Simons, 1996). It also depends on how "jumpy" the subject is (Simons, 1996), either transiently because of factors such as preoccupation, or vigilance (state), or if they are characteristically anxious (trait) (Cook et al., 1991; Greenwald et al., 1991; Kalat, 2001; Simons, 1996). Similarly, people with Post Traumatic Stress Disorder (PTSD), who are more prone to intense anxiety, show a much stronger than normal startle (Butler, Braff, & Rausch, 1990; Shalev et al., 2000).

Of considerable interest in startle research have been those results obtained where the startle reflex was measured after being associated with, and in turn potentiated by, some conditioned, or unexpected fearful stimulus (e.g., Brown, Kalish, & Farber, 1951; Davis, 1992; Grillon et al., 1991; Lang et al., 1990; Vrana et al., 1988). This fear-potentiated startle has allowed researchers to examine the effects of startle on subjects by manipulating and measuring the startle reaction. Threat has also been shown to increase the intensity of the startle response. For example, people threatened verbally with electric shock show an enhanced startle reflex (Grillon et al., 1991; Grillon & Davis, 1995; Hamm et al., 1993). These experiments show that the reflexive blink response is potentiated when startle probes are presented with a contextual cue (e.g., red light—threat of electric shock), when compared to a cue where no threat exists (e.g., green light—no threat of shock) (Simons & Zelson, 1985).

The intensity of the startle has also been shown to be influenced by contextual variables (Anthony, 1985; Graham, 1975; Hoffman & Ison, 1980) and vary widely with attentional demands of a coincident information processing task (Vrana et al., 1988). Furthermore, when subjects are instructed to attend to a startle stimulus, both the onset latency of the startle response and the response amplitude (which is easily measured in animal experiments) are increased (Bohlin, Graham, Silverstein, & Hackley, 1981; Hackley & Graham, 1983).

When a startle stimulus is presented in a different sensory modality from an "attended to" foreground stimulus, startle amplitude is smaller than within the same modality (Silverstein, Graham, & Bohlin, 1981). The response to an acoustic probe therefore has been shown to be smaller when subjects are viewing a slide than when they are listening to a melody (Anthony & Graham, 1983, 1985). Startle responses also vary with changes in attention to foreground stimuli within a sensory modality. For example, in the visual modality, the magnitude of acoustic startle is smaller when presented during engaging, interesting pictorial slides than during repetitive, dull slides (Simons & Zelson, 1985). People also startle readily and violently when attention is focused on some task, when intensely monitoring the environment, when drowsy or falling asleep, or when engaged in deep retrospect (Simons, 1996).

The presence of background noise has also been shown to increase startle. Experiments by Davis (1984) showed a significant increase in startle amplitude with rats that had been exposed to a constant background noise. The longer the exposure and the higher the noise level, the worse the startle.

Familiarity with a stimulus may reduce the likelihood of startling to its presentation and may reduce the violence of the response when it occurs. Sometimes a person may fail to startle to a stimulus that would startle most people because he or she has encountered it often and is thus unusually accustomed to it (Simons, 1996).

2.3.3 Cognitive Effects and Recovery from Startle

Disruption of cognitive and other processes following startle has been studied by several researchers (e.g., Thackray & Touchstone, 1970; Vlasek 1969; Woodhead, 1959, 1969). Results have shown that for most people, recovery from a startle is usually rapid, even from a strong startle, but for some people who startle readily and violently, they recover slowly, trapped in an altered state for a significantly longer period. During this time, attention, which may be undirected by conscious thought, searches for a salient object on which to fix (Simons, 1996). Thackray (1988) showed that mean time to respond to an unexpected event or stimulus may not differ appreciably from mean time to respond to a startling stimulus, however the range of response times to the startling event will greatly exceed the range of response times to the nonstartling, unexpected event. Vlasek (1969), Thackray (1988) and Woodhead (1959, 1969) showed that information processing may be impaired during recovery from startle for periods ranging from 17 seconds to 60 seconds. Thackray and Touchstone (1970) discovered that while response times, except for initial task transition, were largely unaffected by startle, the frequency of incorrect responses (i.e., errors in information processing) was significantly greater in a startled group during the first minute after startle than in a non-startled group. This confirms research by Woodhead (1969), who noted that 30-60 seconds is the period it generally takes for autonomic responses such as heart rate to recover, which may correspond with recovery of cognitive performance (Thackray, 1988). A study by Ziperman and Smith (1975)—one of few field experiments, using hood fly-ups and unexpected air-bag deployments on drivers—found some startle effects, although effects tended to subside within the first 10 seconds (Thackray, 1988).

Perceptual motor performance experiments have also shown some disruption following startle. More complex perceptual-motor behaviour is likely to show maximum disruption during the first 1–3-second period, although significant, lesser, disruption may still be present for up to 10 secs following stimulation (Thackray, 1988). To explore the disruptive effects of startle beyond the initial period, Thackray and Touchstone (1970) studied the recovery rate of continuous psychomotor performance following startle, using a compensatory tracking task over a 30-minute period. Although maximum performance disruption occurred during the first five seconds following stimulation, significant impairment was still present 10 seconds after startle (Thackray, 1988). The disruption in tracking performance extended well beyond the initial disruption caused by the startle and appear to be a manifestation of a longer-lasting, more general physiological and emotional response to unexpected stimulation (Thackray, 1988). Individual differences in the magnitude of performance impairment following startle appear directly related to physiological reactivity to startle, and inversely related to level of prestartle task proficiency (Thackray, 1988). This individual variation in startle was noted by Simons (1996), who showed that some people were particularly prone to startle, a group which he called "hyperstartlers". Vlasek (1969) and Thackray and Touchstone (1970) also showed a correlation in impaired performance following startle, with the greatest impairment occurring among those who were either slowest or least proficient prior to startle. Thackray and Touchstone (1970) found that the high impairment group almost doubled in their tracking error scores immediately following startle. Conversely, the low-impairment group showed little difference between their pre-startle and post-startle levels of tracking error. They also noted an apparent covariation with heart rate which appeared to extend into the first 30 seconds following stimulation (Thackray, 1988). The high-impairment group showed significantly greater heart rate acceleration, but the groups did not differ significantly in conductance charge (Thackray, 1988).

Startle has been shown to have a significant impact on cognitive function in some people. It appears to be enhanced in circumstances where threat or fear are present and the effects of this fear-potentiated startle can be significant for some time. In the context of unexpected critical events in aviation, this impairment in cognitive function can inhibit problem-solving, decision-making and situational awareness at a time when it would be most useful to deal with emergency situations.

2.4 Freezing

2.4.1 Introduction

Leach (2004) studied the effect of freezing or immobility during significant emergencies, both aviation-related and otherwise. His research showed that number of people were so badly affected by this phenomenon that they actually perished in perfectly survivable situations.

In some airline-focused experiments, Muir, Bottomley, and Harrison (1996) examined passenger behaviour during aircraft evacuations and discovered that some people were overcome by “behavioural inaction” and were unable to move to help themselves. This freezing in the aviation paradigm has not been limited to passengers, with several examples of pilots who have exhibited these inaction type behaviours at a time when action was most certainly required. Freezing is a multifaceted aspect of human behaviour. It can manifest itself in different ways and is known by different names. Aside from simply freezing, the terms catatonia, tonic immobility, cognitive inaction, behavioural inaction, cognitive overload, hypervigilance and dissociation can be used to describe the inactivity that an individual shows in certain circumstances. While each of these is a large topic on their own, they are worth clarifying and delineating.

2.4.2 Dissociation

The term “dissociation” is used to describe a disconnection or separation between aspects of consciousness which otherwise would be well integrated with each other (Spiegel, 1994; Spiegel & Cardena, 1991). Dissociated experiences are not integrated into a person’s usual sense of time, place and/or self, and in more extreme forms of dissociation, disconnections between usually integrated functions of memory, identity, and/or perception result in discontinuity in conscious awareness (Lynn & Rhue, 1994; Lyons, 2004).

In its broadest sense, dissociation simply means that two or more mental processes or contents are not associated or integrated (Lynn & Rhue 1994; Spiegel, 1994) and has been described in various ways:

- to characterise semi-independent mental models or systems that are not consciously accessible, and/or not integrated with the person's conscious memory, identity or volition;
- as representing an alteration in consciousness where the individual and some aspects of his or her self or environment become disconnected or disengaged from one another; and
- a defence mechanism that affects such disparate phenomena as nonorganic amnesia, the warding off current physical or emotional pain, and other alterations of consciousness (Lynn & Rhue, 1994, p. 16).

Several definitions of dissociation exist. Nemiah (1991) described dissociation as "the exclusion from consciousness and the inaccessibility of voluntary recall of mental events, singly, or in clusters, of varying degrees of complexity, such as memories, sensations, feelings, fantasies, and attitudes" (p. 250). Spiegel and Cardena (1991, p367) defined dissociation as "a structured separation of mental processes (e.g., thoughts, emotions, conation, memory, and identity), that are ordinarily integrated".The DSM-IV defines the essential features of dissociative disorders as "a disruption in the usually integrated functions of consciousness, memory, identity, or perception of the environment" (Nijenhuis, 2000, p. 8).

Finally, Lerner (1992) described dissociation as "a defensive process in which experiences are split off and kept unintegrated through alterations in memory and consciousness, with a resulting impairment of the self" (p. 398).

In the clinical domain, dissociation has been viewed as a defence mechanism (Cramer, 2000; Lynn & Rhue, 1994; Singer, 1990). It has been used to explain why certain mental contents are not part of an individual's consciousness, as an explanation of the processes through which those contents are removed from memory, or to describe particular elements within the stream of consciousness (Barton, Blanchard, & Hickling, 1996; Lynn & Rhue 1994; Mamar, 2000; Marmar et al., 1994; Van der Kolk et al., 1996).

Dissociative phenomena can alter a person's subjective awareness in distinctive ways, depending on whether they experience a form of dissociation involving memory, perception, identity, physical body sensations or a combination of these (Lyons, 2004). These core dissociative processes have been identified as: dissociative amnesia, depersonalisation and derealisation, identity alteration and somatoform dissociation (Holmeset al., 2005; Hunter, Sierra, & David, 2004; Lyons, 2004). An individual experiencing derealisation may feel as if they were looking at external reality through fog or through a veil and hear someone talking to them as though from far away. Normally familiar places, people and objects may seem unfamiliar or hard to recognise, as if in a dream, and they may report disorientation and an altered perception of space and time (Hunter et al., 2004; Lyons, 2004). Christianson and Loftus (1987) further suggested that, when confronted with distressful events, individuals may narrow their attention and have memory alterations. These attentional changes may, in turn, be involved with alterations in consciousness, including depersonalisation (Baker et al., 2003; Cardena & Spiegel, 1993; Lynn & Rhue, 1994; Spiegel, 1994).

Dissociative episodes may happen automatically and unwittingly, or be purposeful and conscious (Lynn & Rhue, 1994). For example, when an individual encounters a stimulus that is associated with a traumatic event (even a benign stimulus) they may automatically engage in internally-focused attention, or they may purposely use hypnotic-like techniques to have dissociative experiences, such as focusing attention on an imaginary event, perhaps unfocusing their gaze entirely (Lynn & Rhue 1994; Nicolosi, 2009). When confronted with an ongoing danger or threat, a dissociative mechanism is initiated to safeguard the individual's psychological integrity (Cramer, 2000; 2006; Lynn & Rhue, 1994). Within the psychoanalytic framework, such a mechanism is purposeful, although not necessarily conscious, and may be triggered in isolated instances (e.g., when a person is confronted with a disaster) (Cramer, 2000; 2006; Marmar et al., 1999; Lynn & Rhue 1994).

Experimental research has produced some evidence that, when confronted with distressing events, individuals may narrow their attention and have memory alterations (Brown, 2002; Christianson & Loftus, 1987; Lynn & Rhue, 1994). These dissociated attentional changes may, in turn, be involved with alterations in consciousness, including depersonalisation (Cardena & Spiegel, 1993; Lynn & Rhue, 1994; Lyons, 2004).

2.4.3 Behavioural Inaction or Disengagement, and Mental Disengagement

Muir, Bottomley, and Harrison (1996) identified a range of behaviours exhibited by passengers during simulated aircraft evacuations. While some were prone to immediate flight or even altruism, some displayed behavioural inaction (Muir, Bottomley & Harrison, 1996): they gave up and stayed where they were, which in a real accident may have conceivably caused them to perish.

The analysis of several disasters, such as the Piper Alpha oil rig fire, MV Estonia ferry sinking, and the Britair Boeing 737 fire at Manchester airport, has shown that 10–25% of people did little or nothing to escape from danger (Leach, 2004). This totally inappropriate response has also been observed in a number of aircraft accidents and serious incidents discussed later in this thesis. In one case, when an Air Canada DC-9 caught fire, it was clear that some fatalities were located in their allocated seats, and they had seemingly made no effort to exit the aircraft (NTSB 1986a). Similarly, some passengers on board the taxiing Pan Am Boeing 747 that was involved in a collision with a KLM 747 at Tenerife in 1977 were described by their fellow passengers as making little attempt to escape from the burning aircraft (Barthelmess, 1988; Ripley, nd). It is suggested that this behavioural inaction (Lazarus, 1966), where individuals do little or nothing to escape, occurs because they are uncertain of what action is the most appropriate. This response is hardly surprising in view of rapidly changing events in a highly dynamic and dangerous emergency situation (Harrison & Muir, 1989).

Lazarus (1966) attributed behavioural inaction to three possible scenarios. First, it may be due to an individual's perception of the situation, which leads to the conclusion that there is no way of actually preventing the harm anyway; second, when a defensive reappraisal is made and the individual concludes that no danger actually exists; and third where the individual simply does not have the ability or necessary knowledge to make a rational decision (Lazarus, 1966).

Two other allied dysfunctional phenomena which are related to freezing are *behavioural disengagement* and *mental disengagement*. Behavioural disengagement (Carver, 1997; Carver et al., 1983; Knee & Zuckerman, 1998), involves reducing one‘s effort to deal with a stressor, even giving up the attempt to attain goals with which the stressor is interfering. It is reflected in phenomena that are also identified with terms such as learned helplessness (Carver et al., 1983; Garber & Seligman, 1980). In theory, behavioural disengagement is most likely to occur when people expect poor coping outcomes (Carver et al., 1983).Mental disengagement is a variation on behavioural disengagement, postulated to occur when conditions prevent behavioural disengagement (Carver et al., 1983). Mental disengagement occurs via a wide variety of activities that serve to distract the person from thinking about the behavioural dimension or goal with which the stressor is interfering. This might include using alternative activities to take one's mind off a problem (a tendency opposite to the suppression of competing activities), daydreaming, escaping through sleep, or escape by immersion in television (Carver et al., 1983). It is useful to think of the conceptual category of mental disengagement as forming a "multiple act criterion" (Fishbein & Ajzen, 1974, cited in Haddock & Maio, 2004, p. 277) rather than as being a unitary class of behaviour.

Behavioural and mental disengagement presumably function in coping as they do in other domains, such as test anxiety (Carver et al., 1983) and social anxiety (Carver & Scheier, 1986), and in the self-regulation of behaviour more generally (Scheier & Carver, 1988). Although disengaging from a goal is sometimes a highly adaptive response (Klinger, 1975), it often impedes adaptive coping (Aldwin & Revenson, 1987; Billings & Moos, 1984; Cronkite & Moos, 1984; Wills, 1986).

2.4.4 Cognitive Inaction, Cognitive Overload and Concurrent Task Demand

The term "*cognitive load*" is used in cognitive psychology to illustrate the load related to the executive control of WM (Sweller, 1988; Sweller, van Merrienboer, & Paas, 1988). While cognitive load theory is largely concerned with oversaturation during learning environments, the concept of being swamped by too much concurrent and high priority information where the individual is unable to successfully attend to or process the information presented, is the underlying concept in this construct. This theory is widely researched in the attention, working memory, dual-task or concurrent task literature (e.g., Barrouillet et al., 2004; Byrne & Anderson, 2001; Cowan, 1999; de Jong, 1993; Lemaire, 1996; Matthews & Campbell, 2009; Matthews, Sparkes, & Bygrave, 1996; Oberauer & Göthe, 2006; Pashler, 1994; Wickens & Weingartner, 1985).

People who have been involved in various disasters and crises have afterwards described being unable to think of what to do to help themselves (e.g., Harrison & Muir, nd; Leach, 2004; Shaw, 2001). In such cases people may have been insufficiently equipped technically to interpret the dynamically unfolding information which would have allowed them to make a satisfactory decision. Indeed, when people have suddenly become overwhelmed by information, particularly in a stressful situation such as an emergency, then their WMs are likely to be focused more on the sense of threat and foreboding than on constructive plans on how to deal with the problem and effect a resolution (Leach, 2004).

The captain of Qantas Flight 32 openly admitted that there were times following his A380's uncontained engine failure when he was completely overwhelmed by the quantity, complexity, and severity of the information which was encountered in the minutes after the explosion (de Crespigny, 2011). The nature of the uncontained failure led to a stream of ECAM (Electronic Centralised Alerting Module) failure messages, depicting breakdowns in different systems on board. The ability of the crew to mentally process what was happening and to action checklists to deal with these multiple failures was heavily taxed, and an overload of too much ambiguous, confusing, stressful information led to breakdowns in information processing and crew coordination (de Crespigny, 2011).

2.4.5 Tonic Immobility

Tonic immobility was referred to as "playing dead" in the early ethological literature (e.g., Bracha, 2004) and has been referred to as peritraumatic "panic-like" symptoms in the posttraumatic stress disorder literature (Bracha et al., 2004). In common with many other animals, humans occasionally exhibit tonic immobility in the face of serious and unavoidable threat (Gallup, 1977; Gallup & Maser, 1977; Volchan et al., 2011). In contrast to attentive mobility, in which the animal becomes motionless but intensely alert (ears pricked up etc.) (Aston-Jones, 2005), tonic immobility is an unresponsive and extreme reaction to fear, often called shamming death or terror paralysis (Misslin, 2003; Stokes & Kite, 1994). It is generally induced by conditions of fear and physical restriction, the important aspect likely being the perceived incapacity to escape (Bados et al., 2008; Heidt et al., 2005; Moskowitz, 2004).

Tonic immobility may enhance survival when a predator temporarily loosens its grip on captured prey under the assumption that it is indeed dead, providing the prey with an opportunity for escape (Marx, Forsyth, Gallup, Fuse, & Lexington, 2008). It is also a response that may be adaptive in humans when there is no possibility of escaping or winning a fight and is commonly characterised by the behaviour of some victims of violence or sexual assault who exhibit extreme passivity during the assault (Bados et al., 2008; Bracha et al., 2004; Marx, Forsyth, Gallup, Fuse, & Lexington, 2008).

Tonic immobility has been reported by various human groups, from combat soldiers to rape victims (Cantor, 2005; Gallup & Maser, 2005; Peres, Goncalves, & Peres, 2009). Its symptoms include the rapid onset (and equally sudden termination) of a conscious but frozen state featuring severe motor inhibition, tremor, numbness and reduced pain awareness, reduced body temperature, slowed heart rate, and an inability to speak or even scream (Stokes & Kite, 1994).

2.4.6 Catatonia and Catalepsy

Catatonia is considered a state phenomenon, representing dysfunction in a major nervous system process such as motor regulation (Abrams, Taylor, & Coleman-Stolurow, 1979; Gelenberg, 1976; Goldar, 1988; Moskowitz, 2004; Taylor, 1990). Catatonia can be induced by stressful situations and patients have acknowledged that during this state they were afraid of moving, as if paralysed by fear (Moskowitz, 2004). It has been speculated that a link exists between catatonia and factors present in primitive defence reactions against predators. In this case, catatonia might be considered to be a residual and inadequate response (Misslin, 2001).

Catalepsy is a physical condition which is generally associated with catatonic schizophrenia. It is characterised by suspension of sensation, muscular rigidity, fixture of posture, and often by loss of contact with the environment (Gallup & Maser, 1977).

While Moskovitz (2004) suggests that there may be a fear element in the basis for catatonia, most research suggests that catatonia and catalepsy are associated with psychiatric disorders such as depression, schizophrenia and other affective disorders (Abrams & Taylor, 1976, 1977; Taylor & Abrams, 1973, 1977). While people experiencing catatonia or catalepsy may exhibit behavioural inaction, their derivation in psychological disorders suggests that they are less likely to be relevant to the dynamic freezing or inaction type behaviours being studied here (Abrams & Taylor, 1976, 1977; Taylor & Abrams, 1973, 1977).

2.4.7 Freezing

Having discussed several conditions under which an apparent freezing mechanism can be displayed by humans, be it a cognitive or a behavioural inaction manifestation, it is important to make the point that, notwithstanding the possibility that some of the phenomena discussed in this section could occur in pilots, this study is instead focused on that element of the freezing construct which is brought on by the onset of acute stress. Freezing, which is defined in this thesis as the complete absence of body movements, is a normal response of humans and other animals to unavoidable fear stimuli, which commonly occurs as part of the well known fight or flight response (Bracha et al., 2004; Canon, 1929). Prior to discussing this further, however, it is important to differentiate between the freeze in which someone is “overcome and paralysed” (behavioural inaction—e.g., Lazarus, 1966; Muir et al., 1996), with that phenomenon in the literature also described as defensive freezing, which is an immediate and short-lived response (Gray, 1988).

An understanding of the neurological basis of the defensive freezing process is important. Emotional reactions are organised by underlying motivational states, defensive and appetitive, which have evolved to better increase survival (Bradley & Lang, 2000; Lazarus, 1982; Smith & Lazarus, 1990). Emotions have the capacity to elicit a large range of behavioural responses in the body and while research has been done into the neural and other bodily responses to threatening stimuli in particular, considerable work remains to be done. One confounding problem is that a single response associated with the activation of either the appetitive or defensive motivational systems can invoke a range of different responses, sometimes referred to as the “defence cascade” (Lang et al., 1997), which is shown in Fig 35.

Previous discussion has shown that when confronted with a threatening stimulus, the amygdala makes a rapid assessment of this threat, which is then confirmed by cortical processing a few hundred milliseconds later (e.g., Lazarus, 1966; LeDoux, 1996, 2000). Projections from the amygdala then modulate a series of both autonomic and somatic behaviours which facilitate the processing of a threat and prepare the organism for overt defensive behaviour (Campeau & Davis, 1995; Canteras & Swanson, 1992; Chrousos, 1992; Davis, 1992, 1997; Davis, Hitchcock, & Rosen, 1987; de Olmos, 2004; Hamman, Ely, Grafton, & Kilts, 1999; Herman & Cullinan, 1997; LeDoux, 1993, 1994, 1996a, 1996b, 2000, 2003; Phelps, 2006; Whalen & Phelps, 2009).

The amygdala sends a signal from the central nucleus (CE) to ancillary brain parts, including the dorsal and ventral nuclei of the PAG (Benarroch, 2012; Carrive, 1993; Coombes, 2006; Davis, 1992; De Oca et al., 1998; LeDoux, 2000). Should the signal from the amygdala be such that a secondary appraisal process (Lazarus, 1966) has decided that the best course of action to deal with this threat is simply to freeze, then the ventral region of the PAG (vPAG) will instigate a freezing mechanism in the PSNS, which will immobilise the body (Applegate, Kapp, Underwood, & McNall, 1983; Bradley, Codispoti, Cuthbert, & Lang, 2001; Bracha et al., 2004; Brand˜ao, Zanoveli, Ruiz-Martinez, Oliveira, & Landeira-Fernandez, 2008). This freezing process will continue until such time as the threat subsides or some other form of coping mechanism is employed by the continual reappraisal process. The freeze response is typically characterised by a cessation of body motion (immobility) and a reduction in heart rate (bradycardia), accompanied by an orienting response during which the organism is hypervigilant to behavioural cues which might require a fight or flight reaction (Campbell, Wood, & McBride, 1997; Kalin, 1993; Marks, 1987; Schenberg, Vasquez, & DaCosta, 1993).

This freezing behaviour has been described in animals and in humans as one of the phases of the defense cascade (Blanchard, Flannelly, & Blanchard, 1986; Bradley & Lang, 2000; Fanselow, 1994; Lang, Bradley, & Cuthbert, 1997; LeDoux, 1996; Lopes et al., 2009). The cascade model is one method of describing the sequence of appetitive and defensive behavioural responses (see Figure 22).

Figure 22 – Defence Response Cascade underlying the processing of increasingly arousing aversive stimuli.
(Reproduced from Bradley et al., 2001)

In this model, an initial stimulus identification, followed by a freezing period, is then followed by a defensive response (i.e., overt action). Following the initial perception, both threat and arousal state are assumed to increase simultaneously (i.e., in the post-encounter stage when the threat is proximal). As this happens, other processes commence: skin conductance resistance (SCR) rises, startle potentiation increases (due to amygdala-PnC defensive priming) and the heart rate goes up (brachycardia) (Bradley et al., 2001; Coombes, 2006).

There is, however, some variation amongst theorists into the sequential organisation of responses to threat (Bradley et al., 2001). Clinicians refer to the initial response to threat as a hypervigilance stage (being on guard, watchful, hyper-alert or the "stop, look, and listen" response), while ethologists simply call this the freeze response (Gray, 1988). Certainly in the animal world this freeze/hypervigilant stage has some basis, with research showing that prey are more likely to avoid detection while frozen because the visual cortices and retinas of mammalian carnivores primarily detect moving objects rather than colour (Bracha et al., 2004). This immobile, vigilant phase has also been noted by researchers (e.g., Bradley et al., 2001) during human experiments using aversive pictures.

2.4.8 Behavioural Inaction as a Construct

While the subsidence of action which occurs during the initial post-encounter arousal phase is commonly referred to as freezing, this phenomenon clouds the freezing description of people who have demonstrated behavioural inaction as a result of overwhelming acute stress. Certainly in crisis situations, humans have commonly demonstrated this behaviourally paralysed freezing response (e.g., Heaslip, McLeod, Vermij, & Hull, 1991; Leach, 2004). For example, during the Piper Alpha oil rig disaster and the MV Estonia ferry sinking, survivors described seeing people who "just wouldn't move", "were standing still, apparently in shock", "appeared to be paralysed, staring and horrified", "appeared petrified and could not be forced to move" or "just sitting in corners, incapable of doing anything" (Leach, 2004). One survivor of the Estonia also reported throwing lifejackets to people in the water who took no action to put them on or save themselves (Leach, 2004). Further research (e.g., Heaslipet al., 1991; Stokes & Kite, 1994) offers several cases in the aviation paradigm where pilots have frozen at the controls (discussed further in chapter 4).

While considering freezing in the aviation paradigm, Heaslip and colleagues (1991) termed the condition in which pilots exhibit these immobile characteristics "frozen pilot syndrome", and suggest that this phenomenon could simply be a WM issue, where an extreme manifestation of attentional narrowing (Bacon, 1974; Baddeley, 1972; Hockey, 1970) or cognitive tunnelling (Dehais et al., 2010; Gaba, 1992; Speier et al., 2003; Tenenbaum et al., 1993; Woods, Johannesen, Cook, & Sarter, 1994) results in complete disruption of inferential processes. This is somewhat supported by Mandler (1967, cited in Goldberger, 1983), who suggests that the most obvious explanation of inaction or paralysis is that there are "no available action or thought structures to handle the situation" (p. 48). As a contrast to this state, Mandler (1967) has noted how little stress is apparent in highly trained personnel such as astronauts who are equipped with sophisticated mental models of their vehicle's systems and dynamics, and have ready response scripts, plans, action sequences, and problem-solving strategies for almost any conceivable emergency, rendering them practically routine (Stokes & Kite, 1994).

In assimilating these theories, it is fair to suggest that the primary and secondary appraisal processes (Folkman, 1984; Lazarus 1966, 1990, 1999; Lazarus & Folkman, 1984) where a threat is considered both crudely in the amygdala and later cortically in the pre-frontal areas of the brain (Duckworth, Bargh, Garcia, & Chaiken, 2002), may result in a situation where no obvious action-coping strategy is available (Endler et al., 2001), perhaps because the person is unfamiliar with the situation or generally inexperienced in similar events, and the emotion-focused coping/defence mechanism of freezing is therefore employed as a means of internally managing the stressor (Lazarus & Folkman, 1984; Monat & Lazarus, 1992). The freezing construct where people fail to take any action, appearing paralysed, is the type of phenomenon which is of most interest in this thesis. Hereafter this construct is described as behavioural inaction.

While different freezing-type behaviours exist, the behavioural inaction which people exhibit during times of acute stress is of particular interest in the aviation context.

2.5 Denial

2.5.1 The Denial Concept

The term “denial”, in its strict psychoanalytic application, refers to an unconscious defence mechanism which protects an individual against painful stimuli originating in the real world (Freud, 1936; Goldberger, 1983). However, while denial has regularly been described as a defence mechanism (e.g., Breznitz, 1983; Cramer, 2006; Freud, 1936; Goldberger, 1983; Spence, 1983), it has also been described as a coping mechanism (Houston & Hodges, 1970; Lazarus, 1966; Monat & Lazarus, 1991). Both Sigmund and Anna Freud (Freud, 1920; Freud, 1924, 1936, 1962, 1966) explored the concepts of denial as a defence mechanism in the early stages of psychoanalysis, and this has formed the basis of subsequent work.

Denial can be considered a dynamic mechanism for managing a stressful encounter (such as an acutely threatening situation), or it may be a long term strategic tool to avoid an on-going stressor becoming overwhelming (Lazarus, 1966, 1990; Lazarus & Folkman, 1984; Monat & Lazarus, 1991). Certainly the concept of long-term denial in the medical literature is well understood (e.g., Cohen & Lazarus, 1973; Dembo, Leviton & Wright, 1956; Freud, 1936; Hackett & Cassem, 1974; Janis, 1958, 1974; Lazarus, 1998; McDaniel & Sexton, 1970; Sevush & Leve, 1993; Weinstein & Kahn, 1955; Wolff, Friedman, Hofer, & Mason, 1964; Wright, 1960). People who start exhibiting worrying symptoms will often deny their existence until such time as a disease has overwhelmed them and the symptoms are so obvious that either they can’t be denied any longer or other people notice them. Sadly this state of denial can sometimes persist beyond the point where treatment would be effective, resulting in the demise of the individual concerned.

Denial, which has commonly been defined as "the disavowal of reality" (Lazarus & Folkman, 2004, p. 136), has generally been viewed as a very primitive mental mechanism (Goldberger, 1983); a person using denial to cope with a threat is then susceptible to evidence to the contrary which would contradict their view on reality. As a result they are forced to narrow their attention to only experiences which are congruent with their state of denial, closing their mind to what could be threatening (Lazarus & Folkman, 1984; Monat & Lazarus, 1991). This sampling of only "good news" is an effective technique for reducing stress; it does nothing to fix the original problem, which may in fact be worsening as time progresses without it being attended to (Reich, Gaudron, & Penel, 2009).

Lazarus (1983) describes four principles of denial: firstly, that denial can be positive under some conditions and negative under others; secondly, that when denial is used repeatedly there will never be any mastery of the stressor; thirdly, that denial can have value at an early stage of coping when a person's resources are insufficient to cope in a problem-focused way; and lastly, that some kinds of denial are fruitless and dangerous while others are of considerable value (Lazarus, 1983).

Denial is somewhat of a paradox in that no state of total denial can ever fully exist (Spence, 1983). For denial to function as a coping or defence mechanism, it can only be partially effective, and only by allowing some threatening information to register can it orient the person where not to look (Spence, 1983). If all input were blocked – if all denial were complete – the mechanism would probably cease operating and the stressor would be allowed back into consciousness (Breznitz, 1983). Rather, there seems to be a finely adjusted feedback or reappraisal loop created (Gross, 1998; Lazarus, 1966; Lazarus & Folkman, 1984) which determines just how much negative information is permitted to slip through. If too much leakage is allowed, the person becomes anxious and denial is increased; with too little leakage, denial is discontinued and the person is exposed to threats which they cannot tolerate, at which point the denial comes back into operation (Spence, 1983).

When there is nothing constructive that people can do to overcome a harm or threat, that is, when there is no direct action that is relevant, denial and denial-like processes contain the potential for alleviating distress without altering functioning or producing additional harm (Lazarus, 1966; Lazarus & Folkman, 1984; Monat & Lazarus, 1991; Spence, 1983). Nevertheless, some research on worrying suggests that people who use denial as a mode of coping with persistently stressful encounters will experience greater emotional ease on the first occasion but will pay for that ease by continued vulnerability on subsequent occasions (Janis, 1958; Lazarus & Folkman, 1984; Mullen & Suls, 1982; Suls & Fletcher, 1985).

Breznitz, (1983) suggested that there are seven stages of denial which act in a hierarchical structure, with each stage being related to a different stage in the processing of the threatening information. These different levels of denial represent progressive attempts by the individual to protect themselves from the impending danger by resorting to different strategies (Breznitz, 1983). Breznitz suggests that the stages form a Guttman scale (Oxford University Press, 2013), and people will not move backwards in the sequence under any circumstances[2] (Breznitz, 1983). The seven stages of denial are shown at Figure 23 below.

Image removed

Figure 23 – The seven stages of denial
(Breznitz, 1983)

Breznitz (1983) describes these stages below:

[2] Note that the model shows arrows in both directions. This is meant to illustrate the feedback loop which is necessary for continued denial.

> The first attempt to deny starts with the question of personal relevance. A person may perceive the information as threatening, but may attempt to deny its personal relevance. Denial of personal relevance is very well known and very frequent. Often a person will face a danger and yet perceive it as entirely devoid of any personal threat to themselves. Once the belief in irrelevance weakens, the next question concerning urgency becomes more salient. If the denial tendency still persists, the person may then bias the information processing at the next stage, namely, denying the urgency of the danger (p. 261).

As the information continues to penetrate, even the “denial of urgency” solution may turn out to be impossible to maintain (Breznitz, 1983). It will then escalate to the next stage – that of “denial of vulnerability” (Breznitz, 1983; Sexton, Thomas, & Helmreich, 2000). In a situation of object helplessness (which the model is based on), a person who maintains that he can cope with the situation is in fact denying his vulnerability. The diametrically opposite concept to this is “denial of responsibility”, in which a person simply abdicates any responsibility for what lies in store and for not taking any action (Breznitz, 1983).

If the stressful conditions further persist, then the next stage of denial will eventuate – that of “denial of affect” (Breznitz, 1983; Greer, 1992). An admission of not being able to cope leads to anxiety, which is tied to the perception of one’s own emotions and mortality (Freud, 1936; Rachman, 2004). By denying the affect itself, the person may, at least for a while, gain some psychological comfort (Breznitz, 1983). Once affect cannot be denied any longer, it may still be explained away. People may for some time maintain the illusion that their fears, worries and anxieties relate to something other than the primary threat in front of them—that is “the denial of threat relevance” (Breznitz, 1983; Davey, 1993; Lazarus, 1998).

Beyond this, the next possibility of denial comes through distorting the nature of the information itself. This stage is called “the denial of threatening information” (Breznitz, 1983; Levine et al., 1987). By sifting information in a biased fashion, those aspects of the stimulus situation which are particularly threatening can be minimised, reduced, or even avoided altogether (Breznitz, 1983).

If the threatening aspects of the impending danger spread to gradually more and more content areas, the filter itself may become insufficient. Often, in this situation, there is no room for additional denial other than total “denial of information” (Anthony, 1993; Breznitz, 1983).

Breznitz (1983) further suggested that there may be no need for an individual to proceed step by step through the whole process. Indeed, the implications of threatening information may be so overwhelming that a person will advance straight to the latter stages of denial, perhaps fainting or entering emotional shock, which could be indicative of denial of information altogether. Breznitz (1983) described this as quite common in situations of major personal disaster, although some question must remain in these cases whether this is still denial or some freezing type response discussed earlier (e.g., Applegate et al., 1983; Bradley et al., 2001; Bracha et al., 2004; Brandao et al., 2008).

Houston & Hodges (1970) suggested that in a potentially stressful situation, individuals may not report being affectively disturbed either because they just do not perceive the situation as threatening, or because they deny that the situation is disturbing (Breznitz, 1983). If denial is indeed a mechanism which enables people to reduce their experience of discomfort in situations, then denying being disturbed in a stressful situation should lead to better performance than not denying being disturbed (Houston & Hodges, 1970). To test this Houston and Hodges studied the effectiveness of denial in experiments involving students under stress; they discovered that those who used denial performed better than those who didn't (Houston & Hodges, 1970). The experiment was further replicated by Houston (1971), with similar results.

Houston and Hodges (1970) and Houston (1971, 1973) also introduced the concept of "trait denial" as a psychological construct. This enduring trait would be considered to be a contrast to "situational" denial, in a similar distinction to that discussed earlier in trait/state anxiety (Cattell & Scheier, 1961; Spielberger, 1966). While some research (e.g., Fenichel, 1945; Miller & Swanson, 1960) suggests that chronic or consistent use of denial is considered pervasively maladaptive, the work of Houston (1971) and Houston and Hodges (1970) rather suggests that either trait or situational denial can be effective in stressful situations, however, it can be disadvantageous when used in non-stressful circumstances.

Houston (1971) suggested that in an experimental situation in which shock was unavoidable, high-trait-denial subjects (Cattell & Scheier, 1961; Spielberger, 1966) were expected to more readily use cognitive defences and therefore be less adversely affected by stress than low-trait-denial subjects. By contrast, in a situation in which shock was avoidable, it was expected there would be little difference between high- and low-trait-denial subjects in use of cognitive defences, and therefore little difference in response to stress (Houston, 1971). Contrary to expectation, high-trait-denial subjects performed a memory task significantly better and were significantly less physiologically aroused than low-trait-denial subjects across both conditions (Houston, 1971).

Cramer (2006) related denial to intelligence level and ego development by suggesting that high levels of ego development are associated with high intelligence and low use of denial, or alternatively, with low intelligence and high use of denial. By contrast, low levels of ego development were associated with high intelligence and high use of denial, or with low intelligence and low use of denial (Cramer, 2006). Mayer and Salover (1995) further suggest that defensive mechanisms such as denial have a negative effect on emotional intelligence (Salover & Mayer, 1990). This correlates with a study by Dillinger, Wiegmann, and Taneja (2003) that linked active coping methods with personality types. Their research examined Type A personality people, a condition characterised by a competitive achievement orientation, a sense of time urgency, and a tendency toward hostility (Glass, 1977). Type A's preferred active coping and also suppressed awareness of distress emotions (Carver, Coleman, & Glass, 1976; Matthews et al., 1983). Type As also appeared relatively unlikely to disengage from goals with which stressors were interfering (Dillinger et al., 2003).

2.5.2 Denial in Aviation

A NASA study of airline crew performance found that 85% of "textbook" emergencies (i.e., those that the crews had trained for such as engine failures or fires) were handled well, while only seven percent of novel emergency situations were handled with the same degree of success (Peterson 2007). Peterson suggested that when confronted with an emergency situation, unprepared pilots have a tendency to work their way through several mental stages (shock, denial, acceptance) before finally taking action, consuming valuable time which could result in a negative outcome (Peterson, 2007).

Koonce (2002) similarly suggested that when an improbable event occurs many pilots have an initial reaction of disbelief or denial. They may then spend some minutes checking and re-checking for information which would negate the fact that the unusual event has occurred. Koonce suggested that many pilots have difficulty accepting the fact that something has gone wrong with the weather or the aircraft, resulting in an emergency situation (Koonce, 2002). Peralto (nd), who personally experienced an engine failure after takeoff in a single engine aircraft, confirmed this bias. Following a failure at 300 feet (93 metres), he described his mind freezing for what seemed like an eternity and the persistent thought of "this can't be happening to me" (p. 1). From this experience, Peralto suggested that the initial shock and denial after an engine failure after takeoff can easily overcome logical thinking, and even extensive flying experience may not necessarily protect a pilot from this danger (Peralto, nd).

Dillinger et al. (2003) included denial in a longitudinal study on stress coping strategies amongst pilots. In their study they administered a personality test and a stress coping questionnaire (COPE) to first-year students (*n*=50) enrolled in the Professional Pilot Training program at the University of Illinois Institute of Aviation (Dillinger et al., 2003). In this research Dillinger et al. based their definition of denial on that of Carver et al. (1989) who described it as "refusal to believe that the stressor exists or of trying to act as though the stressor is not real" (p. 270), a useful description of the phenomenon. Results revealed that certain personality and stress-coping profiles of student pilots differed significantly, in terms of coping strategies, from previously published norms within the population. Personality characteristics were differentially and significantly related to specific stress coping strategies adopted by student pilots (Dillinger et al., 2003).

These findings support the concept that civil aviation pilots have different personality characteristics to non-pilots (Dillinger et al., 2003). In addition, they demonstrate that such differences can be associated with important stress coping strategies that may contribute to flight-training performance and success within civil aviation. The student pilots scored higher on behavioural disengagement (Lazarus, 1966) but lower on denial and mental disengagement (Carver et al., 1983). They also scored significantly lower on the more emotion-focused support seeking scales (such as seeking support-emotional and venting of emotions). Unexpectedly, they also scored lower in the problem-solving coping strategies (Dillinger et al., 2003).

Table 4 shows the results of the Dillinger et al. study. It compares a sample of coping strategies from the general population to that of one in a sample of student pilots:

Coping Strategy	Development Sample	Student Pilots
	(n=1030)	**(n=50)**
Problem Solving		
Active Coping	11.89 (2.26)	11.24 (1.88)*
Planning	12.58 (2.66)	11.82 (2.55)*
Suppression	9.92 (2.42)	9.50 (1.76)
Support-Seeking		
Instrumental	11.50 (2.88)	11.44 (2.45)
Emotional	11.01 (3.46)	10.00 (3.16)*
Venting	10.17 (3.08)	9.10 (2.91)*
Avoidance		
Denial	6.07 (2.37)	5.28 (1.87)*
Behavioural Disengagement	6.11 (2.07)	6.74 (2.51)*
Mental Disengagement	9.66 (2.46)	8.84 (2.54)*
Acceptance		
Acceptance	11.84 (2.56)	11.22 (2.88)
Growth	12.40 (2.42)	11.82 (2.59)
Restraint	10.28 (2.53)	9.96 (2.07)
Religion	8.82 (4.10)	8.60 (4.11)
Alcohol	1.38 (0.75)	1.36 (0.63)

*Significant difference from development norm based on two-tailed z-test (p<.05)

Table 4 – Coping strategies amongst the general population versus a sample of student pilots (Dillinger, Wiegmann, & Taneja, 2003)

Research by Picano (1990) discovered that when compared to non-pilots, for example, military pilots appear more inclined towards active, problem-solving coping strategies and report a greater tendency to seek information from others in stressful situations. More importantly, they tend to rely less upon emotional support, denial, avoidance or disengagement coping strategies in times of stress.

Besco (1990) introduced a concept called risk denial. This is a term applied to many types of behaviours caused by a considerable number of varied and complex psychological dynamics. It includes such processes as ignoring, tolerating, trivialising and downgrading risks. This denial of risk approximates Breznitz’s (1983) denial of affect and/or denial of relevance, both of which could include the denial of risk (Sjöberg, 2002).

The catch-22 of risk denial is that the aviation system currently has such a large margin of safety that unsafe performance does not usually result in an immediate negative event (Besco, 1990; Boeing, 2012). Therefore, the risk denial behaviour is positively reinforced because the results are either benign or inconsequential. However, the more frequently a particular risk is ignored and/or the greater the number of risks that are ignored, the more the margin of safety will be eroded. Eventually the margin will deteriorate to the point that accidents will occur, although the incredibly wide safety margin that has been built into the aviation industry provides protection from the risk-denying pilot. Most pilots retire before their risk denial behaviour results in an accident (Besco, 1990).

Several high-profile accident investigations have explored the concept of risk denial at a macro, organisational level (e.g., Turner, 1997; Vaughan, 1996). In relating this concept to the aviation industry, Besco (1990), in an airline study, suggested that a false sense of pride and confidence engendered risk denial amongst pilots and that organisations were observed to become so defensive about their invulnerability and infallibility that negative responses to criticism actually contributed to increased organisational risk levels.

As a result of his study, Besco developed an list of common organisational risk denial elements.

- We are so much better than everyone else that we will never make that mistake here.
- It will never happen to us.
- We are above the need to protect ourselves from the kinds of mistakes made by ordinary people.
- Our people are better than that.
- It won’t matter.
- If there was a need to make a change, we would already have made it.
- Laws, rules and regulations are for people who are lacking in good judgment and common sense.
- Good people do it right by instinct; mediocre people need regulations, education and guidelines.
- You don’t need to look for improvements when everything is already going great.
- It’s not false pride when you really have it.
- We haven‘t had any accidents; therefore there is nothing that needs to be improved.
- The accidents we have had are the result of a combination of bad luck, irresponsible individuals and someone else’s negligence.
- We have already implemented all of the worthwhile ideas.
- We are not at risk for those kinds of hazards. (Besco, 1990, p. 4)

Besco's study, and other similar studies (e.g., Turner, 1997; Vaughan, 1996), have shown that denial is a valid, and potentially pathological construct, at both an individual and organisational level. Where it occurs in an aviation context, denial has the potential for critical information to be ignored, or for action to be delayed, to the point where it can adversely impact on safety.

Chapter 3 METHODOLOGY

3.1 Introduction

Chapters one and two have discussed the nature of both the physiological and cognitive issues amongst humans, and particularly pilots, when they are confronted by an unexpected critical event. These effects fall broadly into two categories: acute stress reactions which come about through an appraisal process which determines that the encounter is potentially or actually threatening to personal safety, and therefore requires some coping process to alleviate that stress; and the surprise reaction where fear-potentiated startle leads to an activation of ANS processes within the body which in turn may have a deleterious effect on information processing. This can then lead to impaired situational awareness, problem-solving, decision-making and other effects.

Each of these effects has been shown to be entirely related to each individual's appraisal of the environmental cues which they receive. To understand the phenomena being researched then, it is important to categorise the types of behaviours experienced, and also to interpret the feelings, emotions and recollections of the individuals concerned. To this end the epistemology of the subject studied has necessarily relied largely on personal accounts and interpretation of factual data on behaviours to identify and understand the key factors of these phenomena in real-world settings. This required a qualitative approach, in which interpretative analyses of both case study data and personal accounts through interviews were employed to identify the existence and severity of the pathological behaviours being studied.

Additionally, we have sought to not only identify the existence of impaired behaviour following startle, but to quantify the effects in an experimental paradigm. This quantifiable methodology sought to examine a population sample, with a range of representative participants, whose behaviours could be generalised to the population as a whole. By quantifying these phenomena, some data has been generated which enables analysis of the level of affect pilots are prone to when subjected to the effects of startle.

This study required both qualitative and quantitative means to achieve these objectives. In a qualitative-only study, it would have been impossible to generalise from the data obtained to estimate the prevalence of the phenomena in the population, or how badly affected people were. Similarly, had only quantitative data been generated then it would have been ethically and practically difficult to generate manifestations of the two phenomena under study arising from severe and acute stress reactions, freezing and denial. For that reason it has been necessary to combine these methodologies to obtain both qualitative data and quantitative data.

3.2 Qualitative, Quantitative and Mixed Methods Methodologies

3.2.1 Qualitative Methodologies

Social science involves a diverse mixture of disciplines, including history, psychology, education, anthropology, and sociology (Wiggins & Stevens, 1999). Within each of these disciplines the nature of the research conducted can vary greatly. Within the aviation industry for example, social science research has mostly been aimed at improving aviation safety (Ferroff, Mavin, Bates, & Murray, 2012) and in solving real-world problems such as fatigue (e.g., Caldwell & Caldwell, 2003; Petrie & Dawson, 1997), stress (e.g., Driskell & Salas, 1996; Staal, 2004; Stokes & Kite, 1994), decision-making (e.g., Cook, Noyes, & Masakowski, 2007; Flin et al., 1997; Klein, 1989, 1993), and other non-technical performance issues, such as leadership, teamwork, communication, situational awareness and culture (e.g., Flin et al., 2009; Kanki, Helmreich & Anca, 2010).

Aviation, which is a highly complex, dynamic, and safety-driven environment, demands that the human element in this socio-technical system operates optimally. This complex system requires research which is dependable, credible and transferable (Devers, 1999; McCoy 1988; Luxhøj, 2001; Poses & Isen, 1998; Wiegman et al., 2002) and therefore requires a research methodology that achieves these outcomes.

Social science research has traditionally been a quantitative process, centred on positivistic methodologies aimed at providing statistical data (Ferroff et al., 2012). However, over the last few decades there has been a trend towards a more subjective, qualitative approach (Denzin, 1994), with more and more scientific acceptance and utilisation of qualitative research methodologies.

Ferroff et al. (2012) described an epistemological continuum, starting at one end with the positivist regime (elsewhere termed objectivism and critical rationalism), where exact answers are sought and found. This technique is popular in maths, physics and other fields in which exact data are available to prove or disprove research questions. At the other end of the epistemological continuum knowledge is entirely formed by subjective personal interpretation, and could therefore vary between researchers. This subjectivism is the antithesis of positivism,

relying entirely on human experience. Crotty (1998) suggested that supporters of the subjectivist philosophy believe that there can be no such thing as objective truth. In the middle of these two extremes is a branch of epistemology which falls under the banner of social constructivism. This group of relatively diverse methodologies has been seen as useful for social, organisational and human performance research (Ferroff et al., 2012). Social constructivism methodologies contend that there is some interpretation of results, and that valid meanings could in fact differ depending on circumstances (Vygotsky, 1986, in Silverman, 2001), or between people.
In qualitative research therefore, reality is constructed by individuals within their very own unique, contextual interpretation, which in turn is interpreted by the researcher. This socially-constructed, internal ontology is what builds the epistemic foundations of qualitative research (Joniak, 2001).

In this thesis an interpretative epistemology, using social constructivism methodological processes such as grounded theory and phenomenology have been used to determine meaning from the qualitative elements in the research (see Ferroff et al., 2012). A phenomenological study involves an in-depth exploration of what the participant has experienced, whereas grounded theory involves a systematic approach to data gathering (Ferroff et al., 2012). These techniques have shown to be effective where in depth interviews have extracted autobiographical memory of events, emotions and sensations, to determine the nature and extent of the phenomena experienced (Groenwald, 2004). Likewise, the patterns, common words and phenomena determined from case study analysis are well suited to the grounded theory method (Glaser, 1978).

3.2.2 Quantitative Methodologies

Empirically-based quantitative methodologies have been used in scientific and experimental studies throughout research history. Experimental or quasi-experimental methodologies continue to be used to maximise objectivity, replicability, and generalisability of findings (Harwell, 2011). Experimental researchers are typically interested in predictability and try to make their experiments as free as possible from researcher bias.

Quantitative studies are generally regarded as being deductive in nature, allowing generalisations or inferences from the data obtained (Harwell, 2011). They are also frequently characterised as seeking a “single truth” (Lincoln & Guba, 1985, p. X). They are based on ontology of being objective and material, and an epistemology founded in realism.

3.2.3 Mixed Methodologies

Mixed methods are generally traced back to work by Campbell and Fiske (1959), however it is only over the last couple of decades that the key philosophical and methodological foundations and practice standards have become more commonplace (Tashakkori, 2009).

As a relatively new research process, there is still considerable variation in the acceptance of what constitutes a mixed methods study (Morse, 2010). For example, some authors suggest that to be considered truly of mixed methodology there should be a mixed-methodology research question, qualitative and quantitative analyses and integrated inferences (e.g., Tashakkori, 2009). Others are less stringent and suggest that any study involving both qualitative and quantitative data gathering meets the requirements. Confounding these views further, there is considerable dissent over the notion of mixed methods research at all (e.g., Denzin, 2006; Sale, Lohfeld, & Brazil, 2002; Smith & Hodkinson, 2005). This criticism is based generally on purist, pragmatist or dialectical viewpoints (Harwell, 2011).

Johnson and Turner (2003) summed up mixed methods research best when they suggested that its fundamental principle is that several different types of data are gathered, through different collection strategies and methods, which provide complementary strengths and non-overlapping weaknesses. They further suggest that these varied techniques for data collection allow insights not necessarily available by qualitative or quantitative data only.

3.3 Why Mixed Methods Methodology was Chosen

There are several additional advantages to mixed methods methodologies identified in the research:

- they may help to explain and interpret data;
- they may be used to address a theoretical perspective at different levels;
- the use of both qualitative and quantitative data can enhance validity;
- results may be more comprehensive than singular methodologies;
- qualitative data can explain quantitative results or vice versa;
- qualitative data can be employed to design quantitative instruments;
- the use of both approaches may enhance the integrity of findings; and
- the use of mixed methods may offset inevitable method biases.

(Adapted from Biddix, 2012; Greene, 2007; Fernandez, 2008)

In the current study a mixed methodology was useful for being able to quantify data from the qualitative studies. Qualitative research has established that the phenomena being studied (startle, freeze and denial) have sometimes been contributory causes in past incidents and accidents; however, it has not provided information on how prevalent these phenomena are, or to what extent. By conducting a quantitative experiment, the data obtained allowed the conceptual issues identified in the qualitative phase to be quantified into indicative levels of prevalence and severity. Had the study been qualitative only, this would not have been possible. Had the study only been quantitative, then it would have been impossible practically and ethically to examine the acute stress effects which manifest as freezing or denial processes. In this regard, the mixed methods methodology has allowed a more complete picture of the phenomena under study.

In utilising a mixed methods process, the study involved the following research techniques:

- a thematic, criterion-based review of accident reports, incident reports and other literature, to establish a database of previous incidents involving pathological pilot behaviours during unexpected critical events;
- qualitative, semi-structured interviews with pilot volunteers who have experienced emergency situations or unexpected critical events; and
- quantitative and qualitative data from startle experiments in a Boeing 737 simulator.

A sequential exploratory design was used (Cresswell, 2003). In this strategy, qualitative data were obtained first through a review of the literature, through case study analyses and through interviews. These data were then analysed to create a clear picture of the concepts and their likely involvement in accidents, incidents and undesired aircraft states. Subsequently, a quantitative study was conducted into startle, which was the most prevalent pathological phenomenon (of the three under study) identified in the qualitative study. The data (both qualitative and quantitative) from the experiment were then analysed and the combined data from all the studies integrated and interpreted. This technique allowed clear theoretical concepts to be identified and then tested in situ, to complete the picture of the relative threats of the pathological behaviours under study.

Chapter 4 SYSTEMATIC REVIEW OF ACCIDENT AND INCIDENT DATA

4.1 Methodology

The methodology chosen for this study was a qualitative systematic review. While these are not common in aviation, they are a useful tool for analysing significant amounts of data, particularly where meta-analysis of previous studies allows a coherent summary of previous research to be generated. As there were virtually no previous qualitative studies on startle, freeze or denial in the aviation domain prior to this thesis, accident and incident investigations have been used to explore iterations of the pathological behaviours under review.

4.1.1 Introduction

A systematic review is an overview of primary research studies conducted according to explicit and reproducible methodology which provides a rigorous method of summarising research evidence. This compares with a conventional literature review which summarises and perhaps critiques existing papers, but may not have a specific rationale for including material nor may examine all the literature in the same way. Systematic reviews are useful in providing evidence (or not) of particular phenomena and provide some objectivity because of their explicit criteria for inclusion and exclusion of data.

4.1.2 Objectives of this Systematic Review

The objectives of this systematic review were to examine and review existing research, including extensive databases of accidents and incidents for likely iterations of startle, freeze or denial. A systematic review methodology was chosen because of its objectivity and to provide an unbiased review of published examples of pathological behaviours from a range of sources. This review will be the first such review of pathological behaviours such as startle, freeze or denial published, and as such will add to the data available on these phenomena.

4.1.3 Literature Search

Investigative agency databases of incidents and accidents were examined for iterations of startle, freeze, or denial. Data obtained from aircraft accident reports or incident reports spanning the years 1990-2012 was initially used, from the following sources:

- Australian Transportation Safety Board (ATSB) in Australia
- Transport Accident Investigation Board (TAIC) in New Zealand
- Bureau d'Enquêtes et d'Analyses (BEA) in France

Following a search of accident and incident databases in these investigation agencies, further data was sought by searching common internet based aviation accident websites for other accidents which may be attributable to the pathological behaviours under examination. The following sites were used for this process:

- Airsafe.com
- Aviationsafety.net
- IASA.com
- Planecrashinfo.com

Where accidents or incidents were identified from this search as being likely to contain iterations of startle, freeze or denial, a secondary search was then conducted of the specific reports for that incident/accident within the agency which investigated it. Accidents or incidents used in this secondary search were not limited to the 1990-2012 timeframe. While most fell within this timeframe, there were accidents dating back to 1978 which were included specifically because of the high probability that they contained iterations of startle, freeze or denial. The following investigation agencies were searched in this secondary analysis for specific accident and incident data:

- National Transportation Safety Board (NTSB) in the USA
- Aircraft Accident Investigation Board (AAIP) in the UK
- Transportation Safety Board (TSB) of Transport Canada
- Dutch Safety Board in the Netherlands
- Portuguese Accident Investigation Board (AAPID)
- Aeronautical Accident Investigation and Prevention Center (CENIPA) in Brazil
- Aviation Safety Reporting System (ASRS) in the USA
- Interstate Aviation Committee (IAC) in Russia.

Where accident or incident reports were not available, the specific accident or incident was evaluated using the internet sources cited above. Information from these sources was only used after cross-confirmation from the other internet resources cited above. These searches were conducted manually using the startle, freeze or denial search criteria at table 5 below.

4.1.4 Search Strategy

The accident and incident report abstract databases for each investigative agency in the primary search, and the aviation accident websites in the secondary search, were initially searched for accidents or incidents where pathological behaviour was likely, and to exclude reports which did not fit the inclusion criteria. A full analysis was then conducted of each remaining accident or incident for iterations of pathological behaviours using full accident/incident reports published by the appropriate investigative agency, or multiple-source internet resources where actual reports were unavailable.

The following search criteria were used for each agency's search:

ATSB: An advanced search was conducted using the following search terms:

- Investigation level: Completed
- Type of operation: Air transport high and low capacity
- Investigation level: Level 1-4
- Remainder of fields: All

TAIC: No discriminatory database search capability was available. A manual search of investigation abstracts was made for accident investigations published from 1990-2012. The criteria for startle, freeze and denial at table 5 were used to determine search terms.

BEA: An advanced search was conducted using the following search terms:

- Years 1990-2012
- Type of flight: Public transportation
- Occurrence location: France and other

Remainder of fields: All

To determine whether the pathological behaviours of startle, freezing or denial were experienced in accident and incident reports, the data were examined from a thematic viewpoint, identifying the concepts and behaviours identified as startle, freeze or denial, based on the conceptual identification of each phenomenon gleaned from the literature review. Overall themes, and then a series of specific metrics, were established to identify criteria which could be used to quantify these phenomena. These are outlined in general terms below and then detailed specifically in table 5 below. Only those accidents or incidents which met one or more of these criteria were included in the findings. The criteria provided objectivity and prevented confirmation bias in the analysis.

Startle was identified as a confirmed or probable behaviour when there was some ineffective, inappropriate, or detrimental control input, when there was confusion, breakdowns in situational awareness, or poor decision-making, or when generally pathological behaviours immediately followed an unexpected startling stimulus. When these types of behaviours were observed by others, attributed by accident investigators, or evident through other corroborative sources, then startle was cited as contributory to situation outcome.

To determine the presence of freezing, clear evidence of behavioural inaction following an acutely stressful event was required. This manifestation of "doing nothing when something should be done" is the type of behaviour which typifies a complete overwhelming of the working memory, under acute stress. Behavioural inaction (freezing) was identified from self-reports, observations by others and corroborative evidence of inactivity from other sources.

In determining the level of denial involved in pathological responses, no definitive scales have been universally adopted across the various research fields where denial has been identified, but several scales have been created to try to quantify denial, particularly in the medical, psychiatric, and sex offender paradigms (e.g., Crowne & Marlowe, 1960; Hackett & Cassem, 1974; Gudjonson & Singh, 1989; Jamner and Schwartz, 1986; Levine et al., 1987; Little & Fisher, 1958; Ramanaiah, Schill, & Leung, 1977; Yanagida, Strelzer, & Siemsen, 1981). Of these, the denial scale used by Hackett and Cassem (1974) appears to be most widely accepted, but it is very much oriented towards the denial of myocardial infarction and related medical phenomena.

The Guttman scale of Breznitz (1983) is the only model of denial which appears easily generalisable across a wide range of research fields, and for this reason it was chosen as the most appropriate tool for assessing the presence of denial in the case studies. It was used solely to contextualise the specific criteria discussed in table 5 below.

4.1.5 Inclusion and Exclusion Criteria

4.1.5.1 Inclusion Criteria

Data was almost exclusively obtained from accident and incident reports. The years of data inclusion were for the published report, and not necessarily for the year of the accident/incident. In some cases accidents from prior to 2010 may be still unpublished, and therefore not included, while accidents from the late 1980s may be included because the report was published after 1989.

Table 5 shows the principal themes of each pathological behaviour being considered. It further identifies specific criteria for determining the identification of each behaviour. These themes and criteria, which were determined from the literature review, were used to determine the presence of startle, freeze or denial type behaviours.

Phenomena			
	Startle	**Freeze**	**Denial**
Theme	Pathological startle involves behaviour where a pilot has suddenly encountered an unexpected and/or surprising stimulus, which induces cognitive and physical effects which may momentarily, or for some extended period of up to 30 seconds following the stimulus, result in ineffective, inappropriate, or inaction type behaviours. The startle may be accompanied by physical manifestations such as aversive movement, or involuntary oral responses.	Pathological freezing involves behavioural inaction which results from exposure to some overwhelming stimuli, which are not startling, but involve a degree of threat, and are likely to be acutely stressful.	Pathological denial in this context involves the ignoring of information which could be deemed by an individual or group, as being of significant threat to their safety. It is a coping mechanism which diverts attention to other, less stressful stimuli.
Criteria	• An unexpected and/or surprising stimulus in any modality, which is of sufficient valence to be rapidly noticed. • A surprising stimulus is followed by a response which is either inappropriate, ineffective, or in contravention of rules, SOP's, or training expectations. • A surprising stimulus	• An acutely stressful situation develops, or is likely perceived as developing, rapidly, or over time, but without the presence of a surprising stimulus. • There is evidence, either circumstantially or through self-report, of highly elevated arousal levels. Such evidence often manifests itself in:	• An acutely stressful situation develops, or is perceived as developing, rapidly, or over time, but without the presence of a surprising stimulus. • A threatening stimulus is ignored, or the ramifications of it

	is followed by a period of inactivity when an immediate or timely response was warranted. • The physical and/or mental effects of startle, such as increased heart and respiration rate, have been perceived by an individual and self-reported. • There have been actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident or noted by self-report. • A surprising stimulus is followed by a period where psychomotor skills are significantly degraded from normal performance, or impairment is apparent for some time. • Communication following the surprising stimulus becomes broken, haphazard, or incoherent, for a period of up to 30 seconds.	breakdowns in working memory function, in distraction, in target fixation, in perseverance, in degraded vigilance, and in poor decision making. • While under conditions which are likely to be conducive to acute stress, there is no action taken at a time when action was warranted and/or expected. • There is self-report of being “frozen” during an acutely stressful episode. In such cases the individual concerned may know that they need to do something, but are incapable of doing so. • A pilot has stopped responding and/or failed to take appropriate action, to the point where another pilot has been forced to take control. • A pilot has physically frozen on the controls to the point where some physical action is necessary by another pilot to wrestle control.	are ignored, in association with a period of acute stress. • There is self-report of disbelief or denial during a period of acute stress. • A serious or critical, and possibly deteriorating situation is unfolding, but inappropriate, or no action, is taken to address the problem. This is not freezing behaviour, but rather avoidance behaviour. • The urgency of a developing situation is ignored while under conditions of acute stress. • The perceived relevance of a stressor is ignored when it was actually relevant.

Table 5 – Matrix of inclusion determinants of pathological behaviours

4.1.5.2 Exclusion Criteria

While there are often hundreds of light aircraft accidents around the world each year, the level of investigation of these events may vary considerably, from no investigation to a moderate level of investigation. Often investigation agencies are resource limited, and *may* therefore devote less time and resource to a light aircraft investigation than they would to a transport category accident.

While light aircraft pilots are clearly not exempt from pathological behaviours such as startle, freezing or denial, the reduced investigative rigour which seems apparent in some agencies for these types of accidents and incidents, makes their inclusion problematic in terms of identification of these behaviours. The following accident and incident data has therefore been excluded from the database searches:

- Single engine general aviation aircraft
- Helicopters
- Agricultural aircraft
- Balloons
- Gyrocopters
- Gliders
- Microlights and Ultralights
- Hang gliders

Accident and incident reports from the BEA are generally produced in French, with only a small percentage produced in both French and English. Any reports which were not available in English were excluded from the database.

While only 29 accidents or incidents were found to have a high probability of having definitive pathological behaviours involved, there were a significant number of other accidents identified where startle, freeze or denial *may* have occurred, however insufficient information or evidence was available to confirm with sufficient probability that these behaviours occurred. These accidents and incidents were not included in the data.

The literature review in Chapter 2 of this thesis examined a very wide spectrum of the available qualitative and quantitative research available through academic journals, technical papers and the like. It showed a moderate body of research existed on startle, freeze and denial, however of this data, only seven publications were applicable to the aviation context. Of these, one (Thackray, 1988) dealt with startle, while two (Heaslip et al., 1991 and Stokes & Kite, 1994) incorporated sections on freezing. Besco (1990) Dillinger et al., (2003), Koonce (2002) and Peterson (2007) published papers which included reference to denial in an aviation context, although Besco's work was concerned more with organisational risk denial than individual denial.

This dearth of previous research in the aviation paradigm on these phenomena made little contribution to this study and these publications were excluded from further analysis.

4.1.6 Quality appraisal

Accident and incident investigation around the world, while generally guided in its principles by ICAO Annex 13, often varies significantly due to resourcing, expertise, interpretative and report writing differences between agencies. The end result of these inconsistencies is a wide variation in the quality, accuracy, depth and formatting of accident and incident reports, both inter-agency and intra-agency. These variations in quality may mean that specialist areas, such as human factor related causes of aircraft accidents, may be falsely attributed to other causes, simply because individual investigators, or even whole agencies lack specialist knowledge of pathological behaviours such as startle, freeze and denial. Indeed, the accident reports examined were bereft of data on freezing and denial, and only since the Colgan Air accident in 2009 has there been specific examination of startle as a contributory cause.

The wide variations in accident investigation quality and the apparent lack of knowledge in investigative agencies regarding startle, freeze or denial to date, appear highly likely to have influenced the lack of data available. This would suggest that iterations of startle, freeze or denial are possibly far more common than the accident report data shows.

Where reports have not been available from investigative agencies and internet sources have been used to illustrate a particular iteration of startle, freeze or denial, then these should be regarded with some caution. The quality of the material presented in these sources, while possibly from actual accident reports, is not subjected to rigorous peer review prior to publication. While used sparsely, this data is likely of a lower quality than accident or incident reports from national investigative agencies.

4.2 Results

4.2.1 Results of the literature search

Table 6 below outlines the results of the literature search.

Source	Reports Reviewed	Reports Excluded	Reports Included
ATSB (Australia) (1990-2012)	1901	1898	3
TAIC (NZ) (1990-2012)	331	327	4
BEA (France) (1990-2012)	2308	2304	4
Other (1978-2012)	N/A*	N/A*	18

Table 6 – Results of the Systematic Review

*A systematic review was not conducted of full investigative agency databases in the case of agencies outside the ATSB, TAIC and BEA. Only specific accidents or incidents informed through the literature search were included in this data set.

4.2.2 Inter-rater reliability

To validate the initial interpretations of these behaviours, the data was also evaluated by a second researcher, also with knowledge and experience of both this study and pilot behaviour generally, to rate each of the identified behaviours. Inter-rater reliability was tested by checking for agreement between the ratings of the two raters.

Five differences in attributions were identified, which were discussed in detail by the primary researcher and the reviewer, following which, a third person adjudicated on the five differences, resulting in the following changes being made:

- In event 24B the pathological behaviour was re-attributed from behavioural inaction to startle
- In event 25B the pathological behaviour was re-attributed from startle to behavioural inaction
- In event 26B the pathological behaviour was re-attributed from startle to behavioural inaction
- In event 28B the pathological behaviour was re-attributed from denial to startle

- In event 31B the pathological behaviour was re-attributed from behavioural inaction to startle

4.3 Discussion

4.3.1 Summary of findings from the systematic review

Table 7 lists the accidents and incidents in this section in which the phenomena of startle, freeze or denial were identified.

Event	Flight	Phenomenon Observed
1a	Colgan Air Flight 3407	Startle
2a	Air France Flight 447	Startle
3a	Turkish Airlines Flight 1951	Startle
4a	Pinnacle Airlines Flight 3701	Startle
5a	Air Canada Flight 189	Startle
6a	West Caribbean Airways Flight708	Startle
7a	China Airlines Flight 006	Startle
8a	Air France Flight AF5672	Behavioural Inaction
9a	Air Transat Flight	Denial
10a	American Airlines Flight 965	Startle
11a	Airbus A320, D-AXLA, Perpignan	Startle
12a	Metro III Loss of Control near New Plymouth, New Zealand	Startle
13a	Partenavia Engine Failure near Wairoa, New Zealand	Startle
14a	Partenavia Dual Engine Failure , Auckland, New Zealand	Startle
15a	Saudi Arabian Airlines, Flight 163, Riyadh	Denial
16a	VASP Flight 186 Fortaleza, Brazil	Startle
17a	Cessna 310 Loss of Control after takeoff Tamworth, NSW	Startle
18a	C-5 Accident Dover AFB	Startle

19a	Air Canada Flight ACA 878 Startle following Controlled Rest	Startle
20a	Air Blue Flight 202, CFIT, Islamabad, Pakistan	Startle
21a	Metro III Training Accident, Tamworth, NSW	Behavioural Inaction
22a	Air France Flight 358, Overrun, Toronto	Behavioural Inaction
23a	SAAB 340B Inflight Loss of Control	Startle
24a	Independent Flight 1851, CFIT, Santa Maria, Portugal	Startle
25a	Kenya Airways Flight KQA 507, Loss of Control Inflight	Startle
26a	Swissair Flight 111, Aircraft Fire Inflight, Peggy's Cove, Canada	Denial
27a	Armavia Flight 967 Loss of Control Inflight, Socchi, 2006	Startle
28a	American Airlines Flight 587, Wake Turbulence Loss of Control Inflight	Startle
29a	UT Air Stall After Takeoff Due to Airframe Icing	Startle

Table 7 – Case Study Accident and Incident Database

The preceding review of accidents and incidents described in the literature revealed behaviours which were likely pathological. Of the 29 accidents and incidents outlined in section 4.3.1, most (n=23) meet the criteria which indicate that startle was a contributory factor. Three of the incidents were likely to have involved some element of denial, and the remaining three were attributed to behavioural inaction.

What has been clear in these analyses is that there are times when there appear to be behaviours present which are not uncommon to all three. The fear-potentiated startle response, which occurs following some surprising stimulus, transitions into an acute stress response when the threat persists. In some cases therefore, behaviours typical of denial or behavioural inaction may have occurred soon after a strong startle. The principal difference between the startle cases and the denial and behavioural inaction cases is the lack of a surprising stimulus. It is quite possible for the level of acute stress which induces these phenomena to build quite slowly, or at least to build over a period of seconds, rather than the instantaneous onset of the startle response.

The Colgan Air accident, the Air France Flight 447 accident, the Pinnacle Airlines accident, and the West Caribbean Airways accident are examples of cases in which pilots not only demonstrated ineffective recovery attempts, but made counterproductive recovery efforts that exacerbated the undesired aircraft state which then became unrecoverable. Such behaviours suggest some form of severe cognitive breakdown, which would not only leave competent pilots bereft of ideas on how to recover, but would induce behaviours which were the opposite of those which they had been trained to do in just such circumstances.

Other cases, such as the Turkish Airlines accident, the Air Canada accident and the China Airlines flight border on behavioural inaction, in that the pilots' response was laboured, involved some delay in acting, or was at least ineffectual. While these behaviours may occur to some extent during freezing, which perhaps blurs the crossover between these phenomena, they occurred following a sudden onset of surprising stimulus and suggest psychomotor and cognitive processes affected by startle rather than a gradual build-up of acute stress to the point of overstress.

In the cases involving denial, elements of both strategic and tactical denial were evident. In the Air Transat case, initially in the Saudi Airlines case, and also in the Swissair accident, the denial appeared more strategic and deliberate than a more tactical form of this coping process. In each of these events the pilots chose to ignore cues which indicated a deteriorating situation. Such strategic denial has parallels with medical data which shows people often deny experiencing the symptoms of impending heart attack or developing cancer as a means of coping with the inevitable stress that would be associated with such a condition. Like the person who continues to deny the symptoms during a heart attack however, the Saudi Airlines captain and the Swissair captain chose to ignore the gravity of their situation in the face of rapidly worsening and eventually, unsurvivable fires. Such behaviours suggested a more tactical denial process was in place in these cases, at least towards the end.

Overall, the behaviours typical of startle which have been shown to follow a sudden, surprising stimulus, and the behavioural inaction and denial type behaviours which follow a deteriorating and acutely stressful situation, have been shown in these incidents and accidents to be ineffectual, or counterproductive to recovery. As such they warrant being classed as pathological, and have probably been involved in negative outcomes.

4.3.2 Strengths and weaknesses of the review

The strengths of this review were a comprehensive analysis of incident and accident reports from a cross section of accident investigation agencies across the world. Using multiple sources of data, different investigation techniques, different analysis, and different report writing techniques amongst digfferent agencies, allows for interpretative differences in determining human factors related causes. A narrower search of just one agency for example, may be subject to exclusion of pathological behaviours simply because of that agency's methods.

The weaknesses of this review were the lack of systematic review data from agencies beyond the ATSB, TAIC and BEA, and particularly the NTSB and AAIB. These two agencies investigate a significant number of accidents and incidents and it is likely that a wider review, including data from these two agencies, would yield significantly more results of the pathological behaviours in question. Additionally, while limited in its scope, the use of non-governmental internet resources for accident data, where primary data was unavailable, may have detracted from the overall quality of the review. It is likely that this data was based on original accident reports but this has been unable to be verified and relied on cross-referencing amongst different internet sources.

4.3.3 A reflection on excluded studies

The extensive databases explored during the gathering of data for this study has inherent complications for gathering data of this nature. In the first instance, the mention of the words 'startle', 'freeze' or 'denial', or comparable terms appears to be almost non-existent, pre-2009.

The applicability of certain accidents for inclusion or inclusion at abstract or synopsis stage is also open to both interpretation and for inappropriate exclusion due to the conciseness or absence of sufficient detail, for language reasons, or for a lack of contextual data which would otherwise make an accident or incident worthy of further scrutiny.

It is highly probable that the prevalence of startle, freeze or denial is significantly more common than the data here suggests for a number of reasons. Firstly, there were a substantial number of reports in the various databases where startle, freeze or denial *may* have been contributory to situation outcome, however there was insufficient evidence to show a high probability of their having occurred. There were several accidents and incidents found which involved unexpected critical events where pilots may well have been surprised or acutely stressed by the events, however a lack of information on their reactions in the respective reports made it impossible to determine the probability of a pathological behaviour having occurred without further detailed investigation.

Secondly, the absence of reference to startle, freeze or denial across the databases searched, indicates that knowledge of these topics amongst investigators, and investigative agencies, may be very limited, and therefore would be under-attributed. Finally, a lack of knowledge about these phenomena may have led to causes being attributed to other human factors related issues, and therefore these pathological behaviours may have been seriously under-attributed in the literature.

4.4 Conclusions

While the data included in this study has shown a strong likelihood of pathological behaviours in some accidents, there have also been an abundance of studies which have been excluded where the behaviours startle, freeze and denial *may* have occurred, which were not included for lack of evidence or insufficient information.

Further research into available data surrounding possible further iterations of pathological behaviours may well turn up occasions where these behaviours have been present, despite their not being documented, explored by investigators, or being consequential in situation outcome.

This systematic review has a significant absence of both research and accident data on the topics of startle, freeze and denial, in the aviation industry. Hundreds of accident reports are generated yearly by accident investigation agencies worldwide, however research here suggests that these pathological phenomena have received little attention prior to the Colgan Air Flight 3407 and Air France Flight 447 accidents, where startle and acute stress reactions appeared to play a large part in accident causation. Further research is warranted.

Chapter 5 RESEARCH INTERVIEWS

5.1 Methodology

Qualitative analysis of case studies and real life events can take different interpretive forms. When people have experienced a significant event that has involved a moderate to high level of threat, their recollection of the event is generally quite strong (Eysenck & Keane, 2005). In some cases people may choose not to revisit an event because of strongly negative emotional recollections; however, these people do not tend to volunteer for interviews which may be somewhat painful for them.

Johnston, McDonald & Fuller (1997) suggested that interviewing people is an effective way of determining not just what happened but also why, and can be very useful in human factors related incidents.

Interviews were conducted with pilots between March 2011 and March 2012. Participants were principally airline pilots working for various Australasian airlines and were sourced through airline channels. An email requesting volunteers was sent to chief pilots of the major Australasian airlines or their equivalents, requesting access to their pilot group, with a standard text included. They were asked to email their pilot group with the standard text, which provided some background and asked for volunteers. Additionally, a request for volunteers was sent out through the Australian Federation of Airline Pilots. This provided a relatively wide variety of participants.

The diversity of the incidents involved, the nature of the operations involved in the incidents and the variety of experience levels involved, dictated that a flexible interview technique was employed. The volunteers were interviewed either in person or by phone using a semi-structured technique. This interview technique was chosen for the following reasons:

- it provides much more detailed information than other data collection methods, such as questionnaires;
- reliability is increased by having at least some of the questions standardised;
- replication and consistency is still possible;
- Validity is high. The ability to discuss something in detail and depth can provide meaning around events;
- the ability to ask spontaneous questions is sensitive to allowing participants to express themselves if they wish;

- it enables a more relaxed atmosphere than structured interviews, which encourages interviewee participation and engagement; and
- complex questions and issues can be discussed or clarified and areas of interest can be probed.

(adapted from Woods, 2011).

While some local interviews were conducted face to face, the majority of interviews were conducted by phone due to geographical limitations. Interviewees came from all parts of Australasia and it was therefore impractical to travel to interview each one in person. Interviews were recorded on a digital voice recorder and transcribed by an independent international transcription service. Participants were either given directly, or e-mailed, an information form and a consent form, then asked to sign and return the consent form if they agreed to participate. There was no discernible difference in the level of detail or any perceived reluctance to divulge information between face to face interviews and phone interviews. This has been noted in other studies (e.g., Chapple, 1999; Kavanaugh & Ayres, 1998; Opdenakker, 2006; Sturges & Hanrahan, 2004; Wengraf, 2001).

The interviews started with the participant being asked to provide an outline of a specific event and then focused on the pilot reactions to that event. The interviews involved establishing the facts of each incident, including altitudes, speeds, timings etc., with some phenomenological discussion on feelings, emotional status, physiological arousal levels and cognitive impairment (Moutsakas, 1994). The aim of the interviews was to establish the following:

- the facts about what happened during each event, including heights, speeds or similar relevant information;
- the reactions of the pilot during and immediately after the event;
- any reactionary delays induced by startle, freeze or denial;
- any flight path disturbance incurred as a result of startle, freeze or denial;
- any impact on subsequent actions;
- any other pertinent information which described the event and the pilot’s reaction; and
- any other background information such as previous iterations of similar events which could be used to correlate previous experience to reactionary behaviours.

In all, 40 pilots replied to the request for participants. Each of these was contacted and screened for eligibility; six were excluded because no pathological reaction was mentioned. Typically these excluded events involved inflight engine shutdowns where there was some prior notice and preparation, therefore no associated startle or acute stress reaction was noted.

Of the 34 pilots interviewed, five had had multiple events which they discussed, giving a total of 41 events. Technical problems during recording of the interviews meant that four interviews were of insufficient quality for successful transcription and were therefore excluded from the data. Additionally, two pilots declined to be interviewed but provided written synopses of their events; three synopses were obtained in this way. While this is less desirable than a semi-structured interview, the events contribute strongly to the database and are included as valid data. They are annotated as synopses rather than interviews where appropriate.

Forty events were therefore included in the database and are outlined in the following pages. The interviews were conducted under the guidance of Griffith University Ethics (Approval GU-BPS/11/10/HREC). This ethics approval was granted, and all interviews were conducted, under the express understanding that identified data would not be made available in the public domain. Each event has therefore been summarised by the researcher, with identifiable components removed.

5.2 Results

The following events were taken from interviews with volunteers from around the industry in Australasia. Each event was summarised through analysis of the interview transcripts, and in some cases extracts from those transcripts are included below for emphasis or clarification. The full transcripts are not provided due to requirements in the Ethics approval for participant anonymity.

In determining the presence and type of pathological behaviour in each event, the determinants used in Chapter 4 are used once again, for consistency. The determinants were outlined in Table 5.

Event 1b

Engine Fire

Synopsis

On departure passing approximately 6,000 feet in a twin-engined turboprop aircraft, the first officer (PF) noticed the engine fire light flick on then off momentarily. This was followed a short time later by the fire light coming on once again and staying on. The first officer called for the memory items from the engine fire checklist but the captain was unable to recall what they were for approximately five seconds. He described it as a “memory blank”. During this “memory blank” the captain remembers thinking that it wasn’t really happening.

Extract from the transcript:

> When I had the mental blank, I can remember thinking, I can’t believe this is happening. Like, I can’t believe, it’s just… I’ve got nothing. I can’t remember anything.

Following the five-second memory blank the captain suddenly recalled the procedure and commenced the engine shutdown normally in accordance with SOPs. The remainder of the flight continued normally.

Analysis

This was likely an acute stress reaction which involved a breakdown in memory recall processes for approximately five seconds. This may well have been precipitated by a strong startle as the unexpected critical event (fire light) occurred. The cognitive deterioration which is common after a strong startle was most likely responsible for the captain’s inability to retrieve the fire drills from memory.

During the brief period after the illumination of the fire light where the captain was preoccupied with thinking it wasn’t really happening at the expense of recalling the fire drill, he may have experienced a short period of denial, during which the actuality of the event was temporarily ignored. This appeared to be a conscious thought, however, rather than a pre-cognitive process where threatening information was denied as a coping mechanism. This sense of disbelief is not uncommon, but it does not necessarily imply a stress coping or defence mechanism.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual modality was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

Event 2b

Unextinguished Engine Fire

Synopsis

On departure passing 2,200 ft an engine fire warning occurred. The first officer continued flying the aircraft and the captain carried out the Engine Fire checklist drill from memory. Despite firing two extinguishers the fire warning remained. The aircraft was levelled at approximately 5,000 feet and a dumbbell turn was commenced to return for an immediate landing. The engine was on fire and the fire warning remained on throughout the flight. Despite dumping 10,000kg of fuel the landing was conducted over maximum landing weight. Following the landing a full evacuation was made.

The first officer reported a momentary sense of “disbelief” when the fire bell first went off, but it passed very quickly. He also reported considerable temporal distortion, with things that he thought had taken some considerable time actually being achieved in much less time. This was determined by analysis of the FDR in the ensuing investigation.

The captain was unable to find the engine fire checklist in the QRH and had to give it to the second officer to find.

Analysis

The event was successfully handled, despite being acutely stressful. Both primary pilots appear to have experienced a moderate level of startle, which may, in concert with the enduring severe stress effects of an unextinguishable fire, have contributed to some breakdown in cognitive processing in both pilots.

The temporal distortion experienced by the first officer was typical of some cognitive disruption and the elevated arousal levels that would be likely experienced during such a critical emergency. His perception that things took much longer than they did in reality was indicative of the high arousal state that he was likely experiencing, but it had no significant impact upon the situation outcome.

The captain may have been impaired as a result of both the startle and the enduring acute stress he was experiencing. This was perhaps manifested by his inability to locate the Engine Fire Checklist, which is something he would normally do without problem in regular simulator exercises. The QRH is a series of checklists which covers virtually all emergencies in the aircraft. This particular checklist was arranged alphabetically; however, the captain was looking under the "E" section of the index for "Engine Fire" as opposed to looking under "F" for the various "Fire" checklists. The captain eventually abandoned his search and handed the QRH to one of the second officers to get them to find the correct checklist.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.

Event 3b

Rejected Takeoff Delay

Synopsis

During the early stages of take-off the first officer noticed and called the attention of the captain to a large flock of birds ahead. Given that the speed was relatively low at the time, he thought that the captain might elect to reject the take-off, however the birds then split up into two groups and the captain elected to continue take-off. One group of birds then flew into the path of the aircraft and a multiple bird strike was experienced at just below 80 knots. One bird was ingested into an engine which created a surge and partial loss of power, which in turn induced a sideways yawing motion.

SOPs for this type of aircraft suggest that a decision to reject the take-off should be made for any abnormality if the speed is below 80 knots and above 80 knots for any fire, engine failure, damage or other condition which renders the aircraft unflyable. (Speeds below 80 knots are known as the low-speed reject regime and above 80 knots are known as the high-speed reject regime.)

Despite the obvious problem the captain took no action and continued the take-off roll, accelerating through 80 knots in the process and into the high-speed reject regime. The first officer was somewhat surprised by the captain's decision to continue the takeoff and suggested that they stop.

This finally prompted the captain to initiate a high speed reject which was completed correctly in accordance with company SOPs.

Interview excerpts:

> And sure enough, they hit, and then I thought, well, we haven't called 80 knots yet, he's definitely going to stop, and after that, there was no reaction. And I thought, hmmm, okay, we're definitely not going to be continuing, we've now gone through 80 knots, we're well below the V1, and as I said, it could have been both engines, given that the bird flock split, and I thought, "I'm keen for the aircraft to stop and I thought, we're okay, we're below V1", and yes, that's when I sort of said to him, "we can stop". And he didn't react.
>
> What shocked me was that, because I said we hadn't made the 80 knot call, we weren't at 80 knots, I thought, oh, he's definitely going to stop. That was my instinct. I thought, as I said, first thing was [expletive deleted], we've hit them. And then my instinct was okay, we're going to stop. And then it didn't happen, and yes, that's ... I was shocked, because now I thought, oh no, were not stopping. Is he frozen, or is he thinking we should continue? But he didn't enunciate "continue" and he was just not reacting in any

> way. So that's when I was quite concerned and I thought I need to prompt him and get some information to get a flow of action happening, one way or the other ...

Analysis

This was an incident in which a relatively new captain was suddenly confronted with a critical situation. Despite obvious cues of multiple bird impacts and engine damage on one side, the captain, who may have been startled by the event, entered a period of behavioural inaction at a critical stage of the takeoff. Rather than making an immediate assessment of damage or likely damage, the captain did nothing for some seconds, all the while continuing to accelerate from the low-speed reject regime (below 80 knots) to the high-speed regime (above 80 knots). The ramifications of an abort from the low-speed regime are few, however the potential problems from high-speed aborted takeoffs are far greater, with tyre and wheel damage, runway overruns and schedule disruptions all possible.

The captain in this case may have been startled by the sudden appearance of the birds and when the impacts occurred was temporarily overwhelmed by acute stress. The cognitive impairment from the startle, accompanied by very high levels of arousal, may have contributed to his inability to make an abort decision. In the end it appears that it was only the first officer's prompting which overcame the cognitive disruption and allowed a decision to be made. Thereafter, the actions of the captain appeared sound, as he recovered sufficiently from the impairment.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following data.

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.

- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in working memory function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, no action was taken when warranted and/or expected.

Event 4b

Catastrophic Engine Failure

Synopsis

On a twin-engined jet aircraft during the climb out passing approximately 11,000 feet, the number one engine suffered a catastrophic and uncontained failure. A large quadrant of the high-pressure turbine had developed some cracking and let go, exploding out through the engine with a very loud bang. The engine snapped in half at the shaft and seized. Flying debris from the failure also damaged the leading edge of the wing. The pilot interviewed actually thought there had been a terrorist bomb explode on board—it was that loud.

Following the explosion there were a few seconds when the PF instinctively controlled the yaw and roll induced by the failure. This involved an intuitive application of aileron and rudder to keep the wings level. He then described a period of approximately five seconds when his mind "went blank", before he was able to consciously apply the required engine failure procedures.

Following the failure the non-flying pilot went through the engine severe damage drill memory items, with his actions being confirmed by a supernumerary pilot who was sitting in the centre jump seat. This was then followed up by the engine severe damage checklist which was read from the QRH. During the reading of the checklist it became apparent that the engine fire handle (the fourth item in the memory drill) had not been pulled as required. This could conceivably have resulted in fuel continuing to be fed to a severely damaged engine, possibly resulting in a fire. Other associated systems such as hydraulic and electrical systems would normally be shut down through the pulling of the fire handle and these were still in an operative mode. Failure to shutdown these systems could also have led to an increased risk of fire.

Excerpts from the transcript:

> What's interesting is of course it came with a very loud noise, so it was like someone had fired a shotgun just outside of the window, if you like. It was very loud and the

> aircraft lurched … The aeroplane rolled somewhat and all the energy just sort of went through the strut and into the aeroplane and the autopilot dropped out and so, yes, there was a ... There was a startle ... certainly a startle factor when it went.
>
> You're overloaded completely and you can't think of anything and all of a sudden it starts to, yes, well, I'm still alive, you know, and then you get a chance to start to assess the... you know, what's actually happening.
>
> …the more interesting thing was when it came to trying to figure out a speed for flying because now you're landing with no leading edge, no new trailing edge, that took a long time to figure out because it actually is quite hard to think about serious problems when you're kind of ... You know, you can do the things that are automatic but it seemed to me that the things that required some real concentration, sort of analysis, that's quite hard to do when you've had a real ... you know, like a shock like that.

Analysis

Evidence suggests that this incident involved a substantial startle. While the initial noise would have generated a startle reflex, the continued threat posed by the impact of the failed engine on the flight path would have likely continued the startle into an enduring level of elevated arousal. While potentially problematic, the five or so seconds of "blank mind" did not appear to be consequential in this incident because the yaw and roll induced by the failure was easily and intuitively managed by the very experienced pilot. Had the handling characteristics of the aircraft been severely impaired by perhaps greater damage to the wing on one side, however, then the ability of the pilot flying to "think through a solution" to manage the condition could conceivably have been severely impaired during this "mind blank".

The failure of the non-flying pilot to action the engine fire handle during the memory drill items and also the failure of the third pilot to confirm that the action had not been completed were further evidence of impairment, typical of an acute stress reaction following a strong startle. Omissions, mistakes and other errors are common during acute stress reactions (Stokes & Kite, 1994) and in this case both pilots involved in actioning and confirming the drill missed a fundamental step which could have had serious consequences.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 5b

Pilot Froze During Approach

Synopsis:

During an instrument approach in cloud the PF set up a high rate of descent which caused the aircraft to descend lower and lower below the required glideslope. Despite numerous verbal and violent physical attempts by the support pilot to get the other pilot to correct the situation, the high rate of descent continued until the aircraft broke out of cloud approximately 200 feet above the ground. The flying pilot who had been in a frozen state all the way through the approach suddenly regained his composure and pulled back violently, narrowly missing an apartment block by mere feet. He then continued on to make a poor landing.

Transcript Excerpts:

> … Once we entered the cloud bank it all went … started going bad, but very subtly. I didn't notice anything at first, but I was, you know, just watching the instruments, and, you know, localiser, air speed's good. Catching the slope, you're half-a dot low. I'm monitoring, on localiser, air speed's a little bit increasing. You're a full dot low.
> …. you are going a dot and a half low, on localiser, air speed is beginning to increase, "captain, are you paying attention?" And you know, back then I don't remember the exact verbiage for ramping up the discussion to get somebody's attention, but it was

something along those lines. “captain, are you …? Did you understand me?” Can you hear me? You know, that kind of stuff. You know.

Yes, so, we went two dots low, and, you know, at this point I’m tapping him on the arm, and tapping the yoke, and I’m saying, “captain, we’re two dots low.” And all of a sudden we went full scale … Air speed went over the barber pole … And we started nose-diving. Now, you know, at this point, I’m now hitting him. I’m saying, “captain, what are you doing? [unclear] ... go round now; go around. Go around. Go around”, you know. .. And he’s big. He’s a big, big boy, you know, six-five, 300-pounder. His hands covered the yoke, you know, and I’m trying to get the controls and there’s no way. I mean, he’s locked on. And I finally realised that he had white-knuckled the throttles and the yoke, and eyes wide open, but he wasn’t responsive at all, so, you know, this is way beyond pilot incapacitation at this point. I hit the guy, and, you know, I hit his hands as hard as I can, you know, and I’m thinking, you know, this is not going to end well at all. I started to go into a very, very non-response, almost like going into the foetal position. And feel like, because I knew I was about to die, and … we popped out of the clouds, and at that point I reached into my flight bag, and we had those big Maglite [torch], five D-cell battery, almost like a baton, thing. I think I’m going to crack him in the head a last time, and take the controls if I could. We popped out the clouds at 200 feet, and there is an apartment block. That was the image, the first image we see, is us screaming towards this apartment block. He wakes up at the very last second, and I’ve got my hand raised, just about to crack him, when he pulled back on the controls. We went over the top of this apartment block at ten feet.

I gave way, stopped, and he said, where are we supposed to be? What’s going on? Now, I slammed the flashlight down on his hand, and I said, go around now. He firewalls the throttles, pulls back on the controls. We go vertical. I’m thinking, oh, shit.

He does a negative G bump over at about three hundred feet, and we’re engaged on the glide slope. Everything in the cockpit, and I mean, everything, flight bags, coffee, checklists, clipboards, everything that isn’t nailed down, pegs to the ceiling as we do this negative G bump over at three hundred feet. Everybody in the back is screaming bloody murder. You hear shit banging around back there, and I’m thinking, you know, it’s truly … we call it a tie floater. My tie was up in my face.

We pop back out of the clouds again, and I’m thinking, ”Oh my God, here we go again.” There just happened to be the runway. So we landed …

Analysis

This was a very severe case of behavioural inaction; a complete freezing of a very experienced pilot. In this case the PF appears to have become completely overwhelmed by the stressful events unfolding, and simply froze for an extended and critical period. The cause of this impairment is indeterminable, but the marginal weather, possibility of diversion, and challenging instrument flying conditions, may have been contributory. It appears that had the aircraft not popped out of cloud then it would simply have flown into the ground, or into a building, despite the best efforts of the first officer to take control.

Apparently this was not the first instance of this pilot succumbing to overstress, as the first officer later found out, but at the time he was unaware of previous history. The cognitive disruption which leads to a sustained period of behavioural inaction such as this must be severe, and is surely borne out of a complete mental overload induced by the stress of the situation. What seems to most pilots to be a straight forward ILS approach was so acutely stressful to this pilot in this instance that his WM appears to have become completely overwhelmed by anxiety.

The fact that he had a death grip on the controls also signals some severe physiological reaction, which was a possible side effect of SNS activation at a very high level. The inability of the first officer to distract him or to remove his hands suggests that adrenaline was involved in the captain's system (Marsden & Meadows, 1970). This powerful hormone has accounted for seemingly superhuman strength in some cases (e.g., Wise, 2009) and the strength of his grip suggests the presence of something beyond normal.

This was a critical event which would in all likelihood have been catastrophic had the captain not suddenly found sufficient mental strength to comprehend the situation and pull up (albeit severely), at the last moment. It appears that the visual cues which became available to him once the aircraft broke clear of cloud allowed sufficient cognitive response to recognise the immediate danger and to recover.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following data.

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, no action was taken when warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, to the point where another pilot was forced to take control.
- A pilot physically froze on the controls to the point where another pilot had to wrestle for control.

Event 6b

Engine Failure After Takeoff

Synopsis

During preflight checks on a 1950s-era training aircraft, a foam rubber plug was inadvertently left in the air intake on the side of the engine cowling. This led to an engine failure at 600 ft after take-off. During the power-off descent, stall buffeting occurred as speed was reduced to extend the gliding distance. A stall from low level would not have been survivable and this gave the pilot an additional fright, on top of the initial startle when the engine stopped. The aircraft crash-landed in a paddock, destroying the aircraft and injuring the occupants.

Interview excerpts:

> Well, I knew a stall … the [aircraft type deleted], when they stall, they quite often drop a wing, and to drop a wing and spin from only three hundred or four hundred feet would be normally fatal. It has fatally injured a lot of [aircraft type deleted] pilots over the years.… I was probably the most startled I've ever been in my life. You know? It was a huge startling event … But initially I was just totally stunned to the point where I found myself disbelieving actually almost what had happened. But very quickly I reacted in as much as I put the nose down to get a gliding speed happening. And then I realised that yes, the engine had actually stopped, so I sort of reacted first.

Analysis

This was an incident where the experienced pilot was strongly startled by an unexpected and sudden, critical event. The ensuing effects on cognitive processing were quite profound, with an initial period of abject disbelief for around five seconds (which appears relatively normal and unrelated to psychological coping per se), followed by some mishandling as the aircraft very nearly stalled while turning back towards the airfield. This had the effect of inducing a secondary startle, which would have likely been fear-potentiated, as the prospect of a loss of control and spin from low level suddenly presented itself.

The pilot definitely felt startled and showed signs of impaired information processing even after the aircraft had crash-landed. The lack of expectation and the severity of both startles (the engine failure and the stall buffet) quite probably were enhanced by the enduring effects of elevated arousal. The pilot certainly felt very stressed all the way down and made some consequential errors indicative of cognitive impairment.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.

Event 7b

Flaps Retracted Instead of Gear After Takeoff

Synopsis

Immediately after take-off in a jet airliner the first officer inadvertently moved the flap lever to the up position, retracting the flaps instead of raising the landing gear. This created a situation where the aircraft came very close to stalling. The captain, who was the Pilot Flying observed the speed tape turn red in reaction to the flap lever position and immediately lowered the nose and levelled out at 240 feet above ground level. This allowed the airspeed to increase sufficiently to avert a stall, although the stick-shaker did activate, indicating that the aircraft was very close to a full stall. Once airspeed was recovered the aircraft carried on to destination with the first officer somewhat stunned for some time.

Extract from the transcript:

> When I got going, he didn't really understand what he'd done wrong … You know, what he did was totally erroneous, he knew that too. He just could not understand what he'd done wrong … And he nearly fell out of the sky, obviously. And he was in tears … He knew damn well the situation, and how serious it was. He didn't make light of it at all, he just sat there quite quiet. We were going to [destination deleted], and he was very quiet all the way [there] basically.
> [Interviewer] He was unable to comprehend?
> Without, yes, without a doubt. Totally unable to comprehend….You know, total confusion - of that, I'm sure, at that point.

Analysis

In this case the first officer committed a grave mistake which came very close to resulting in an aircraft accident. Following the incident he appeared somewhat bewildered for some time and in discussion later, was unable to comprehend what he had done. The captain reacted instinctively to the visual and tactile cues presented and saved the day; he was, however, affected by symptoms typical of PTSD for several days after the event. His reactions to the startling event were actually very good, although probably intuitive, and he admitted to being preoccupied with the event for some time.

The first officer likely suffered degraded information processing as a result of the severe startle he experienced. The realisation of the gravity of his mistake was probably a significant factor in this, and the preoccupation with the event, coupled with post-traumatic stress, resulted in him being less than effective for the remainder of the flight.

This was a situation where a human error created an unexpected critical event. The captain reacted intuitively to the flight information presented and didn’t appear to be too badly impaired, however the first officer clearly suffered enduring cognitive deterioration for some time afterward.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 8b

Hijack

Synopsis

During a bank charter flight the flight crew was hijacked by two on-board security guards. While the captain, who was flying, managed to maintain a reasonable level of normal function, the first officer became very stunned and took virtually no part for around 10 minutes. The crew were diverted to an uninhabited island and held hostage for several hours.

Interview Excerpts:

> All right. Well, basically, yes, there was … I think a few seconds of confusion. It felt like a long time, but just to register actually what he was doing to us, because … Yes. So it was a few seconds of uncertainty what actually was happening, because I just thought he was … he knocked me on the back of the head. I thought, oh, is something wrong in the back? Or he's not happy, or he's uncomfortable, or something, because there's two security guards on board. And, but then, as soon as I saw the gun come into the cockpit, I realised that, yes, this is pretty serious.
>
> so the adrenaline, let's say it went pretty high, but then, I think both the initial reaction for [name deleted] and I was looking forward and not giving him too much eye contact.

Analysis

This type of event would clearly have been very concerning for most people. Having suddenly been confronted with a critical situation, with no obvious positive outcome guaranteed, the crew would have been in a very acute state of arousal for some time.

The captain, after initially being hit on the head, was startled by the impact and the sight of the gun. However, he managed to divert his attention to flying the aircraft and this probably assisted in mildly reducing his arousal state. According to his own assessment, he didn't suffer too many cognitive effects from the startle, but certainly felt somewhat stressed, particularly given the unknown outcome.

The first officer, on the other hand, appeared to the captain to have suffered a fairly severe reaction to the initial startle. He withdrew almost completely, displaying symptoms of behavioural inaction for some 10 minutes or so following the initial hijack. He did not participate in the execution of the diversion at all for some time and just sat there staring ahead.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. While initially the first officer may also have been startled, the duration of the pathological behaviour suggests the main pathological behaviours exhibited by the first officer are typical of behavioural inaction. These determinations are based on the following data.

Captain

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

First officer

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, no action was taken when it was warranted and/or expected.

Event 9b

Engine Failure

Synopsis

In the cruise at 7,000 ft in a light twin-engined aircraft, one engine coughed once, which led the pilot to believe there was a fuel problem. He instinctively reached down to crossfeed fuel; however, the engine suddenly failed totally. Following 5-10 seconds of stunned disbelief, the pilot regained his composure, the engine was secured, and a visual approach and landing was made at the destination.

Excerpt from the transcript:

> It's almost ... it's almost like a blank. It's almost like a blank mind. Trying to decide, well not trying to decide, there's probably another way, but it's just a blank mind while you're ... I guess I was being diverted from thinking that there was a fuel issue … "I didn't get a fright. It wasn't a fright at all. Certainly a blank, like I say …

Analysis

In this case the pilot suffered a very rapid, unexpected event. While he suggested that he wasn't startled by the event, it is quite possible that he was but either recovered quickly or just doesn't recall that reaction. It appears that a few seconds of behavioural inaction followed, with the feeling of disbelief being the overriding thought pattern during this time. Once the initial "blank" period passed, the pilot then appeared relatively unimpaired and conducted the securing drills and diversion very well.
In this case the behavioural inaction experienced had little effect on situation outcome.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual and olfactory modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 10b

Engine Shutdown

Synopsis

In the cruise at 7,000 feet in a light twin-engined aircraft, a major oil leak in one engine was noted, requiring an engine shutdown. Following 3–6 seconds of feeling "dumbfounded", the engine was secured and a visual approach and landing was made at the destination.

Transcript excerpts:

> But once again, it was a case of sitting there and looking at it dumbfounded … This was between about three and six seconds, because you realise that it's oil, it's pouring out, and there's a hot exhaust in there. So, there's a bit of delay there, but a bit more desperation as well.
>
> Yes and so there was obviously some adrenaline going on there, if it sort of got my voice in the PA. Which I didn't even really notice it. But … [one of the passengers, his boss] just said "Oh, I just sort of picked it when you did your PA, you know."

Analysis

A few seconds of behavioural inaction and disbelief were experienced. This was associated with a moderate level of startle with enduring levels of elevated arousal, which manifested itself in a wavering voice during a passenger announcement. The 3–6 seconds of self-assessed delayed processing were inconsequential to situation outcome.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual modality was experienced, which was of sufficient valence to be rapidly noticed.

- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 11b

Ejection as Aircraft Flew Into a Mountain

Synopsis

During a low-level navigation sortie in a high performance military jet, the pilot was distracted while trying to change the frequency on a radio in the rear left of the cockpit and the aircraft flew into the top of a mountain. The pilot noticed the terrain immediately prior to impact and initiated an ejection, which occurred after the initial impact. The decision to eject was an intuitive one as the approaching terrain was perceived by the pilot at very close range.

Excerpt from the transcript:

> In that time I decided to eject. When I saw the ground rush coming up I decided, that's it, get out, and the time that it took ... I'd actually clipped the mountain by the time Id got out, it was going that quickly, you know, and the impact was so small, it felt like ... You know, when you go through a cattle grid in a car? ... It's sort of that feeling. That's what I felt and I thought, no, I must get out. And then the psychology took over. You know, there was a whole lot of stuff that happened which I'll describe to you. Anyway, the aeroplane pitched forward slightly and I timed it perfectly because I ended up ejecting vertically instead of down towards the ground and I left the aeroplane doing about 580 knots and landed on the side of the mountain with my parachute open. I broke my leg, compressed my back vertebra and just lay on the mountain waiting for the guys to come and fetch me.
>
> A week later (after a fellow pilot had failed to eject), when I saw the ground rush up, I'd made my decision immediately, so from that moment onwards I was in go mode and when I clipped the mountain, I could hear myself screaming. I could hear like this terrible screaming and at the same time I was... Your brain, it like pops a circuit breaker. It pops a fuse from the shock reaching your body …"
>
> "The shock that's coming into your eyes of such a rapidly deteriorating situation, it stops your body from receiving that shock and it says, no, don't worry, you're okay. I visually saw a picture of myself lying next to my new wife in bed at home and I thought, don't worry, just having a nightmare, you'll be waking up any minute now and you'll be fine in your bed at home … And so there was this lie, you know, that was

presented straightaway and at the same time I knew that I'd already made a decision, get out. And why have I made that decision? Just pull the handle anyway. That was what saved me. I remember pulling the handle and the screaming, I could hear it. The aeroplane was starting to ... There was a flame that came out through the centre panel in the cockpit and it was ... It forced my head back and straightened my back perfectly for a nice ejection, you know, because you can imagine I was probably getting thrown forward at the time … And I had my back beautiful and straight and off I went and, yes .... So, it all came back to reality when I was out of the aeroplane, feet facing forward and the parachute trying to slow me down and I kind of just had enough time to stabilise the parachute and then avoid a big rock and then I hit the ground and broke my leg on impact at the knee joint. And then just an amazing calm came over me. It was just like the most incredible clarity that my decision-making was absolutely clear, clear, clear and I just sat there and the first thing I did, I looked to see if I could move my toes and then I could see, yes, I'm moving both my toes. It wasn't really sore at the time, my left leg, and I thought, "okay, I'm alive. Am I bleeding?" I looked around. No blood. Okay. I could see the wreck of the aeroplane down in the valley and I was sort of a thousand feet up on the side of the hill and then I thought, okay, survival, take my water out. You're told to drink lots of water in shock ... to avoid shock, you know.
... and then the guys arrived in the helicopter. I talked them in on my radio and my flares and then they fed me with morphine and at that stage .... When the guy arrived I realised that my left hand was still holding the seat pan handle. Yes. I'd actually broken the cable. It's a nine-ton force and I'd actually broken the cable off when I ejected.
[Interviewer] So, when you look back how many seconds prior ... you know, before impact would you envisage that was?"
I would say five seconds.
…. But also I think the interesting thing was .... The temporal distortion, you know what that's all about, obviously … That was a big factor because I got the feeling that, don't worry, there's still plenty of time. You know? But why am I trying to reach this handle? And there was this stretch of time where I could see the ground coming up and my hand trying to reach the bottom handle. It was actually from the .... well, to the handle. I'm thinking why am I trying to reach this handle?. It was about a timeframe of miniscule seconds and I thought "okay, just pull the handle anyway" and that's what I did.
So, the temporal distortion was like a lie, you know. It was saying, don't worry, it'll be fine. And there was also that lie that happened in my brain saying I'm lying at home with my wife. You know? Relaxed.
…. In that moment, ah, definitely. I felt this sense of security. Don't worry, you're fine, I can see you lying next to your wife in bed. You know?

> You know, there's a real sense of ... a false sense of security and .... You're actually in denial because your body's saying, no, don't worry, it's not happening.

Analysis

While the reaction to eject seems to have been an instinctive one, perhaps based on some recognition-primed decision-making which had been reinforced at a safety meeting just a week earlier, there was an interesting few seconds of both acknowledged temporal distortion and also of some form of denial. The temporal distortion is a common effect when faced with imminent crisis (Carson, 1983), with some people suggesting "they saw their life flash before their eyes". It appears that under the acutely stressful imminence of an impending and recognised life-threatening event that some people have an element of autobiographical memory recall. In this case that period had little effect as the ejection had already been initiated, but as the pilot concerned noted during the interview, this was not always the case, with some pilots leaving it too late to eject (Carson, 1983).

In this case there was a (self-described) period of denial immediately prior to the ejection. This appears to have been a high-level denial in which threatening information is denied and internal attention is turned to more pleasant autobiographical thoughts. This may well have been a dynamic coping process for what was a critically close life-threatening event. The few moments between deciding to eject and actually hitting the hill before the ejection was initiated would have been highly stressful, so it is quite possible that the pilot's brain has appraised the situation as overwhelmingly threatening and employed a mechanism for relieving that stress. This brief disavowal of reality with a transition to internal loci of attention proved very effective in this case, as a deflector of immediate life-threatening stress.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of denial. It is highly likely that he also experienced startle, however the rapidity of the action taken and the situation outcome make this difficult to specifically identify. The determination of denial is based on the following:

Underlying theme:
A pilot appears to be tactically ignoring information which could be deemed as being of significant threat to their safety.

Specific criteria:

- There was self-report of “disbelief” or denial during a period of acute stress.

Event 12b

Engine Surge

Synopsis

During the cruise in a medium twin-engined aircraft, one engine fuel control computer started malfunctioning, resulting in the engine surging and a yawing motion occurring. The fuel control computers were turned off and the problem disappeared but a degree of startle was experienced.

Excerpt from the transcript:

> The first thing that I got was a loud pop. And I think it was from the right engine and then that sort of started picking up and became worse, and the yawing followed very quickly afterwards. So, and then I started obviously, looking at engine gauges and things like that. You could see, I think it was torque on the right engine going crazy, with the, with the popping and the yawing and stuff as well at the same time … and the temp was going all sort of funny as well like when I was getting the popping and banging etc. So there was certainly quite a few indications. I think the fuel flow gauge was up as well, it was going crazy, so there was certainly no lack of information being presented to me that something was going wrong. It was just the fact that I was a bit, you know, taken unawares of what was happening … But certainly initially the surge of adrenaline shot up and [unclear] things to start, I was thinking, you know, pulling myself together … I probably suggest at least ten or fifteen seconds …. in which I was going okay what the hell is going on? What am I going to do? What do I do first? And am I going to die? …

Analysis

The definitive adrenaline surge and delay in information processing are indicative of a strong startle followed by elevated levels of arousal. The pilot was preoccupied by another task and was heads down at the time, so the suddenness and strength of the startle was quite profound. Research suggests that concentration and vigilance can potentiate the effects of startle, and this may have contributed to the severity of the reaction (Simons, 1996).

In this case the pilot experienced a moderate period (10–15 seconds) of confusion following the startle. The cognitive impairment was in keeping with research which shows impaired cognition following a strong startle.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 13b

Depressurisation Caused by Second Air Conditioning Pack Failure

Synopsis

With one air conditioning pack already unserviceable, the aircraft was dispatched under the approved minimum equipment list (MEL). During the climb, approaching FL280, there was a bang, followed by a master caution. The single remaining pack had had a failure, with an ensuing bleed air leak, which had then been automatically shut down by the system's pre-programmed protocols. Following an initial period of confusion, the captain assumed control and the first officer commenced running the Bleed Leak checklist, which was the annunciated failure. The first step in this was to turn the bleed air on that side off for three minutes, which had the effect of removing air to the only remaining pack. This eventuality hadn't been considered by either pilot until some time into the three-minute period when the captain suddenly became cognisant of the fact that the aircraft was steadily depressurising. A rapid descent was then initiated to 10,000 feet, with the aircraft reaching this altitude just as the cabin was climbing through 10,000. This meant the aircraft was essentially depressurised.

Excerpts from the transcript:

> And my original, my initial thought, this is why when you mentioned it I thought ”Oh, God, I’ll tell you that”; I thought “Oh no, that’s bull…t. That’s not real.” You know, my immediate thing was to deny it……
>
> Big, big adrenaline hit, far more than I thought I would, far more. I would like to think, you know, we all like to think that we’re going to be, you know, captain cool in an emergency but after I looked at it and comprehended and thought, ah, you’re kidding, and you know, ah no way, you know. Bang! A real, you know the fingers, the shaky stuff ... Of course, yes. And there’s nothing you can do about it. It’s just instant, real, some basic survival stuff, you know.

Analysis

Following the initial bleed leak, the captain recalls a short period of denial, where he had a sense of disbelief that the event was happening. This was typical of the cognitive clarification phase described by Wheeler and Lord (1999), when new and traumatic information is slowly integrated into cognition. While a form of temporary denial, it is a common means of coping with sudden and threatening information (Wheeler & Lord, 1999).

It was also likely that there was a startle as the master caution went off and the nature of the problem became apparent. This may have had some effect on information processing because the ramifications of the failure were not considered by either pilot at that stage. The initial checklist item (turn bleed off and wait three minutes) created an opportunity for the captain to sit back and analyse what had actually happened, and it was then that the ramifications of turning the bleed off suddenly occurred to him. At the time he got a very strong startle, with an associated increase in arousal level and a strong hit of adrenaline. The realisation created an awareness of exactly what was happening, leading to an almost recognition-primed decision to descend as quickly as possible (Klein, 1993). Recovery from this strong startle appears to have been quick, with no other deleterious effects on information processing being recalled. The emergency descent was conducted in accordance with SOPs and the aircraft was safely levelled at 10,000 feet.

The first officer described later how he had suddenly come to the realisation of what was happening when the aircraft was passing 13,000 feet on descent and he noticed the cabin altitude rising through 9,700 feet. Until then he hadn't fully comprehended what was going on, but he noted feeling a big surge of adrenaline around that point. He appeared to recover quickly from this startle and contributed normally thereafter.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural and visual modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 14b

Major Oil Leak Leads to Engine Shutdown

Synopsis

Shortly after takeoff in a light twin aircraft, the pilot noticed a significant oil leak appearing on one side. There was a short period of disbelief and the pilot initially wondered what to do, having fairly limited time on type and due to the complexity created by his location in a mountainous area. He eventually made the decision to shut the engine down and return to land, but the decision process was complicated by the emotional state he was in, due largely to inexperience and the criticality of his position in mountainous terrain.

Extract from the transcript:

> Yes, this is not real, this can't be happening, yes, and then you look back and it's just pissing oil down the rear strut. So, it was quite interesting because I was inexperienced. What worried me then was that I'm in the highlands, you know. I had to go back and

land at an airstrip at 5,500 feet and normally that's without a pissing aeroplane. So again, I had not enough experience to know how I would do it. It was all just theoretical, you know, you'd just done your endorsement round the circuit area a few months before, so again the same simplistic stuff; do I leave it running till it goes boom and then I'm dealing with it as a failure, or shut it down now as a precaution, that sort of, I had to ask myself those questions.

Yes, this can't be right, no, this doesn't happen, yes, the denial that people have. There's black smudge down the wheel spar, you know, but you still deny that it's really happening. Ah, it can't be that serious, it's just a little, it might be a little left over, rationalising, just a little bit of oil left over just coming out of a service, you know. Ah no, they probably just forgot to do something, you know, trying to find other excuses. And then no, it's still...

Analysis

In this incident a fairly inexperienced pilot, who was operating in demanding terrain, was suddenly presented with a threatening situation, which required some critical decision-making. His initial sense of disbelief was a coping process which provided some cognitive relief while he slowly assimilated the complexity, seriousness and potential implications of the situation.

He also described a considerable surge of adrenaline, no doubt resulting from a strong startle, which endured into an elevated level of arousal. The cognitive disruption which followed was characterised by indecision as he was suddenly confronted with a very high stakes choice: to shut the engine down while it was still intact or to leave it running and possibly suffer a catastrophic failure. This period of consideration was hampered by the immediate threat of poor performance at high altitude in mountainous terrain.

The eventual decision to shut the engine down and return was a fair one, but had been laboured, and the subsequent return to land was done with very elevated arousal levels and a strong sense of trepidation. Ground agents reported the pilot's voice as sounding calm on arrival, but he admitted that was far from how he felt.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual modality was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 15b

Fuel Control Unit Failure

Synopsis

While en-route at 14,000 feet, a fuel control unit failure on one engine in a medium twin-engined aircraft led to a loss of engine control, resulting in the engine producing more and more power. The surge in power created considerable noise and a strong yawing movement, both of which induced a strong startle and on-going adrenaline effects in the pilot. Despite there being no checklist for such an event, the pilot eventually shut the engine down and continued the remainder of the flight on one engine without further complication.

Extract from the transcript:

> Adrenaline, what do I do? Again, the thing I found, I don't know if you, I've found in my career that usually when things have gone wrong it's not in the checklist. It's not scripted. The way that failure was, it was, I just lost control of it and it was slowly giving more and more power to the point of it was going to blow itself up. It was just pumping more and more fuel, more and more torque, more and more ... I thought okay, I'm going to blow up; I've got to shut it down. So I thought well, that's not in any checklist, you know … It was a few seconds of no, that can't be right type of thing, what do you do, and then the recognition that yes, it is real and just basically going through the drill and it worked out perfectly. Once, after the initial reaction it was fine.

Analysis

In this incident the pilot was suddenly confronted with a very threatening critical event with startling visual, auditory and tactile stimuli. The sudden increase in engine noise and the sudden increase in yaw would have provided a very strong startle, which endured into an elevated level of arousal with a strong surge of adrenaline.

There was an initial period of disbelief as the suddenness of the failure created an instantaneous change from normality into criticality. This disbelief quickly passed as the comprehension of the developing situation called for some expeditious intervention. While there were no doubt strong after-effects of the startle and the ongoing stress effects, in this case, despite there being no checklist for a runaway fuel control unit, the remedy for the malfunction was clear-cut. The decision to immediately shut the engine down was initially a little laboured, but eventually became almost recognition-primed (Klein, 1993), as there appears to have been little time spent on problem-solving or weighing of options. In all likelihood, had the pilot spent much more time analysing the nature of the failure and the options available to address the problem, then the situation could have deteriorated rapidly.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 16b

Delayed Rejected Take-off

Synopsis

During take-off in a twin-engined jet, the captain had the perception that there was something wrong with the thrust being produced by the engines. He started talking to himself as the take-off continued, but eventually closed the thrust levers and commenced the rejected take-off procedure. As the aircraft slowed he made no attempt to stop or to alert the cabin, but continued taxiing without any communication to the first officer, ATC or the cabin.

Excerpt from the transcript from the first officer:

> And you know it took quite … he was having this, he wasn't talking to me, he was talking to himself, and then it was, you know, by the time you've got a fair way further down the runway, but it's still probably before 80 knots still, that he's just closed the throttles and given it away.
>
> …. Yes, well we never, we never did stop, we just sort of kept taxiing and wandered off. So I got on the PA and sort of, I got the girls and told [name deleted] not to stand up, and not, you know, to stand them down, if you like, and then a quick plan of what we're doing and sought information from him as what he would like me to do, you know.
>
> …. So it was, his stress level after we'd parked and pulled the brake on and disembarked everybody, was just off the, off the roof. And including the guilt, you know, I'm going to call a QC and get on to the union and make sure ... he was worried that he was going to get persecuted.

Analysis

In this case, as the captain accelerated down the runway, he apparently started having some doubts about the level of thrust being produced by the engines and started rationalising it verbally. This went on for several seconds as the aircraft continued to accelerate down the runway.

After verbalising his doubts for some time, the pilot made the decision that he was going to reject the takeoff, but never alerted the first officer or the cabin crew thereafter. The aircraft slowed and taxied off but he still made no communication and it was left to the first officer to advise ATC and to call the cabin crew to advise them to remain seated.

This incident was interesting in that the captain had never had a serious malfunction requiring a rejected takeoff before, and as the environmental cues started to tell him that something was wrong he clearly had to go through some justification process, verbalising his thought processes and rationalising his decision-making process. This was obviously a stressful process for him, but the lack of aircraft performance must have reached some threshold in his mind at which it was unsafe to continue and he simply closed the thrust levers, raised the speedbrakes and manually braked the aircraft until it slowed sufficiently to taxi clear. However, the after-effects of this somewhat traumatising event weighed heavily on his mind to the point of distraction, and he failed to communicate his intentions or to comply with SOPs until the aircraft reached the gate. Even after the passengers had disembarked, he was clearly preoccupied by the ramifications of his decision and was suffering from elevated arousal levels.

While the captain made a valid if somewhat laboured decision to reject the take-off, it appears that the stress associated with this decision had some ongoing deleterious effects on his information processing. His lack of compliance with SOPs and non-communication were a form of behavioural inaction and, while not critical to situation outcome, could have been problematic had there been other complicating factors such as a brake fire or issues with ATC.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, there was no action taken at a time when action was warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, to the point where another pilot was forced to take control.

Event 17b

GPWS Warning

Synopsis

On a night departure from an airfield surrounded by high terrain, the aircraft experienced a GPWS "Pull Up" warning which was probably generated by a well-known but problematic hill in the departure area. Rather than instinctively reacting to the warning by commencing the terrain escape manoeuvre, the captain did nothing, trying instead to rationalise the warning in his mind. It wasn't until the experienced first officer intervened that the captain was spurred into action. From there on the actions were accomplished in accordance with SOPs, however the lack of action following the hard terrain warning was potentially problematic and lasted for several seconds.

Excerpt from the transcript:

> So we started the turn and then we got the GPWS … it's an old-fashioned aeroplane, not very reliable, because it was just a bit of a hiccup with this hill obviously. And I, my thought process was no that's not real, this isn't happening, we've done, we've done this the same way every time. The aeroplane is performing, you know, this is my thought process which might have only taken seconds, the aeroplane is performing properly, we're at the DME, we're at the right height, the IVSI, the aeroplane's pulling up. So while I was thinking all of that, the FO, who again was a very experienced FO, just went [makes noise] and then he shouted "drill". So I was procrastinating and rationalising why this wasn't real and why we weren't ... We hadn't lost situational awareness, and doing all the ... basically, what I was doing, was doing all the wrong things, I was being logical and practical but the whole idea of that thing is to ... you've stuffed up and you don't know it And as soon as he did that he, you know, I'm going, he just went bang and I then thought, God you're on. And then we launched into it and pulled up and made sure the gear and flaps [were] up and went through, you know, the climb thing until it stopped and climbed to the minimum safe altitude (MSA) and had another think about it. But the interesting ... Yes, I did not go straight to drill stage even though it was quite obvious we'd pull up, you know, yes.
>
> Completely surprised, completely surprised, yes. You know, the hindsight was, it was only a warning, but it was night, it is [country deleted], you do have a smaller circling

area by exemption on that particular runway. You know, don't muck with it, don't play with it, and I had to wait for the FO to initiate.

Analysis

In this case the captain, who was moderately experienced, suffered a strong startle when confronted with an unexpected critical warning. Pilots are trained repeatedly to react intuitively to GPWS warnings at night or in cloud, but his behavioural inaction following the event belied that training. There was possibly some cognitive impairment following the startle as he tried to rationalise the warning in his mind. Rather than simply making a recognition-primed decision (Klein, 1993) to commence the terrain escape manoeuvre, he prevaricated for several seconds, and may not have done anything for some time had the first officer not interjected and forcibly recommended the escape manoeuvre.

This behavioural inaction in the face of a real terrain warning at night could have been critical to situation outcome had the first officer not intervened. The delayed reactions following the strong startle and the resulting impaired decision-making were typical manifestations of cognitive impairment and were fortunate in this case not to lead to an adverse outcome.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.

- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 18b

Gear Failed to Extend

Synopsis

On approach passing 1000 feet the landing gear handle was lowered but the gear failed to extend. A missed approach was made and another attempt to lower the gear was made using the alternate system. This was also unsuccessful. The aircraft then diverted to a secondary airport where an approach was made with the landing gear up.
Excerpt from the transcript: (IV = Interviewer comment; IE = Interviewee comment)

> IV All right, so when he realised that there was some sort of problem, you brought it to his attention. Was there any sort of a delay or anything like that, and sort of trying to figure out what was going on, do you think, before you made the decision to go around?
>
> IE It was sort of, it wasn't straightaway. There was probably a five or ten second pregnant pause, but it was sort of we were getting pretty close to the DA by then …
>
> IV …..Any sort of adrenaline flowing, do you think?
>
> IE ... yes, a little bit. I remember when we were circling, going round the circuit, we started to run the QRH and pulling handles and things, I did notice the heart rate starting to get up and you know, get that sort of time, time stands still, sort of thing. You just sort of truck along going through the motions, and you sort of feel like you're working a little bit more on autopilot than you are on actually thinking about things sometimes, I think …

Analysis

This event was clearly a stressful emergency which was generally well handled by the operating crew. On approach, at approximately 1,000 feet, the captain called for "gear down", but the gear failed to lower. The failure was reported by the first officer; however, there was a period of several seconds before the captain made a decision to conduct a go-around. Once the decision was made, the aircraft had to be manoeuvred clear of another aircraft which had commenced its take-off and was climbing out in close proximity. Once clear, the aircraft was re-circuited and an alternate method of lowering the gear was tried unsuccessfully. Under the alternate method of lowering procedure, handles must be pulled out in two stages, requiring substantial force. The first officer, who had only practised this procedure in the simulator, only managed to pull the handle to the first stop and the landing gear failed to lower as a result.

Once the gear failed to lower via the alternate method, a sound decision was made to divert to a nearby secondary airport where the aircraft held for a short time to burn off fuel then made a successful gear-up landing. No-one was hurt in the landing although the aircraft was badly damaged.

Of interest in this event is the initial delay in going around on the first approach. Clearly when the first officer noticed that the gear had failed to lower there was an element of startle experienced, but when the condition was brought to the attention of the captain there was a significant delay in making the decision to commence a go-around. In this case it is highly likely that the captain experienced a sudden increase in arousal, accompanied with startle. The cognitive impairment common after startle was a possible contributory factor in the delayed decision to commence a missed approach. The realisation of a significant technical failure with flight safety implications was probably instrumental in a spike in emotional arousal which created a short period of behavioural inaction.

Following this period the crew performed well, with the exception of the alternate gear extension, which was probably a training issue. The first officer reported feeling somewhat stressed, with an elevated heart rate typical of an elevated arousal level, and also reported a level of decreased cognitive ability, meandering along "on autopilot" which possibly suggests he was suffering from some cognitive impairment. Whether this impairment contributed to the failed alternate extension attempt is unclear.

Following the successful gear-up landing the first officer started to evacuate the aircraft but was distracted for several seconds and even stopped to return to the flight deck as he realised he did not have his tie on. This lack of rational prioritisation in the aftermath of a major emergency is typical of some behavioural aberrations reported elsewhere (e.g., Leach, 2004) and both the captain and first officer reported suffering the effects of PTSD for some days after the event.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following information.

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 19b

Near Miss with a Large Jet

Synopsis

A C&T captain was training a very experienced captain who was new to the company and type. While climbing to cruise altitude the C&T captain noticed a heavy jet in close proximity and immediately pressed the altitude hold. The Captain under training was initially a little affronted, until the C&T captain pointed out the MD11 passing by just 800 feet or so above them. The captain appeared quite badly affected by the near miss and took some time before he was able to continue. The C&T captain provided guidance and the captain eventually resumed the climb, albeit considerably shaken.

Excerpt from the transcript:

> … His reaction was, he was stunned. He was stunned, like you said, for about, I'd say a good minute. We had to stop climbing and then we kept on going once it was clear. And he just shook his head, couldn't believe it. His first reaction of me overriding him was, what the [expletive deleted] are you doing? Because we've known each other for quite a while, he goes, thanks for picking that up, so he was apologetic.

> It was his rig but he, sort of, I ended up having to take over because he sort of froze. He looked out the window and he just couldn't believe it. He was in no man's land, I guess. So I brought him back into it and said okay, we're clear to climb, let's go back up.

Analysis

This was a near miss with a heavy jet which happened before the common use of ACAS (Honeywell, 2003). Due to an ATC error the incident aircraft had been cleared to make a climbing turn, but the separation had been misjudged and the two aircraft passed in quite close proximity. Had the C&T captain not intervened, the aircraft would have come very close to colliding.

The effect on the captain was profound. He clearly received a very strong startle when he saw the heavy jet and suffered some significant ongoing stress effects as a result. The behavioural inaction he exhibited following the event was for a considerable period, with a substantial decrement in participation for up to 60 seconds. In this case it was fortuitous that the C&T captain had spotted the aircraft, anticipated the close pass and intervened before the situation became critical. Had he not done so then the consequences could have been catastrophic.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual modality was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 20b

Distracted by Helicopter

Synopsis

While on approach to land at an uncontrolled airport a helicopter pilot in the vicinity advised that his passengers would like some aerial footage of the aircraft as it made its arrival. As the aircraft was established on final approach the captain became preoccupied with the helicopter as it hovered off to one side of the approach path. The captain, who was PF, started getting high on profile as the helicopter diverted his attention, despite the first officer trying to get his focus back on the landing. The first officer continued to reassure the captain that the helicopter was well clear; however the Captain appeared to fixate on the helicopter to the detriment of his own flight path management. The first officer eventually called for a go-around, but the captain refused, electing to continue the approach. The aircraft landed well into the runway but stopped before the end.

Excerpt from the transcript:

> … And I said "he's clear, check your profile." And he kept on pulling back and pulling back and going, and I said "your profile is, the chopper's clear", you know." He started to focus in on the helicopter saying "get the chopper away." I said he's one mile away, he's keeping clear, he's confirmed. The guy had, sort of, gone into a tunnel vision. It was a really, really ugly approach and I said go around because he was way off the profile and he wouldn't go around. He refused but he was, it was a really ugly approach. He landed halfway down the runway. The [aircraft type deleted] is capable of stopping pretty quick but that was a very ugly approach because he came off profile when he took his focus off and away and he didn't trust me and what the helicopter pilot had actually told him.

Analysis

This was an incident in which the pilot became distracted from his principal task to the point of behavioural inaction. By focussing on a task-irrelevant stressor, which had no significant bearing on his landing, he deviated significantly from profile to the point where the first officer became quite concerned and suggested he go around. This was refused and the approach was continued, however it was not until the perceived threat from the helicopter had passed that the captain reverted his attention back to the runway and made a poor landing well down the runway.

The captain in this case was clearly concerned about the proximity of the helicopter, even though it was described as well clear by the first officer. His preoccupation was indicative of an elevated arousal level, with an element of perseveration notable in his preoccupation. The behavioural inaction displayed was quite concerning as it led to an undesired aircraft state, with the aircraft getting very high on profile. This was never adequately recovered and a suggestion by the first officer to go around was dismissed, also a concerning development. The fortuitous recovery, albeit with a long landing, could have been disastrous had the profile recovery not been initiated when it was. Had the helicopter's position been further upwind, it is questionable whether the distraction could have persevered beyond a recoverable point and whether the captain, in his elevated state of arousal, would have continued to try and land or whether he would have been able to make a rational decision to go around.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, there was no action taken at a time when action was warranted and/or expected.

Event 21b

Failed to Respond to EGPWS

Synopsis

On approach in cloud into an area of high terrain, a ground proximity warning ("Terrain, Terrain, Whoop, Whoop") sounded. The first officer, who was flying, took no action. The captain told him to go around and he simply raised the nose, without adding additional power, or completing the normal terrain escape manoeuvre. The captain was forced to take over and completed a go-around to minimum safe altitude.

Excerpt from the transcript:

> And really all I can remember is … we were in IMC and the GPWS gave us a terrain-terrain whoop-whoop [unclear] … Yes, and basically, the FO who was the pilot flying ignored it … And – yes. He probably ignored, the first couple, he ignored it and then it carried on. He sort of looked at me and, I mean, I hate recalling it now but I said to him, go around or something like that. And he didn't do anything and … Then I reiterated it. He kind of raised the nose but didn't increase the power … So I took control, and I brought the nose up and pushed the power up and did the appropriate go-round …

Analysis

This was an incident where a first officer was suddenly confronted with an unexpected critical stimulus. It appears likely that he suffered a strong startle, followed by a period of behavioural inaction. Even when the captain told him to go around, the cognitive disruption he was experiencing as a result of the startle had impaired his functioning so much that he was unable to action the instruction.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following information.

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 22b

Startled During Stall Warning Recovery

Synopsis

During a simulator exercise the PF levelled off at 3,000 feet and allowed the speed to decay to the point where the stick-shaker went off. He became very startled and raised the nose to 45° nose up. The simulator was frozen by the instructor before the aircraft stalled completely.

Excerpt from the transcript:

> This was only maybe a couple of months later [after the Colgan Air accident] and a guy does exactly the same thing in our simulator. And I was thinking, holy shit, this could happen to us too.
> Well, you know, if you pull the nose up to forty-five degrees in a stick shake, you've lost situational awareness completely….I mean, even in a bloody light G you wouldn't pull it anywhere near there….I mean, if you're forty-five degrees like that, the ADI's going to have those big green chevrons pointing downwards, isn't it?

Analysis

This was a very interesting incident because it mirrored the actions of the captain in the Colgan Air Flight 3407 accident at Buffalo, New York (NTSB, 2010). In that case the captain likely became badly startled by an unexpected stall warning and had immediately pulled up, resulting in a fully developed aerodynamic stall and a subsequent loss of control, leading to a catastrophic accident.

In this case, the first officer levelled the aircraft at 3,000 feet and allowed the speed to decrease to the point where the stick-shaker went off. This clearly created a strong startle, and in the cognitive disruption that followed, he immediately pulled up to 45°, precipitating the onset of a full stall. Had the C&T captain not intervened, the aircraft would likely have entered a (simulated) fully developed aerodynamic stall.

The severity of the pilot's reaction indicates a major breakdown in cognitive function. The standard recovery to a stall warning is to lower the nose and apply full power. His actions were exactly the opposite and had this occurred in the actual aircraft it could have been catastrophic, as they were at Buffalo.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There have been actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident or noted by self-report.

Event 23b

Catastrophic engine failure in a large jet

Synopsis

This incident was also described by one of the other pilots on the flight deck in an earlier account (see Event 4b). It involved a large jet which suffered a catastrophic engine failure during the climb. The failure was very sudden and loud and produced a significant rolling and yawing motion. A significant startle was experienced by all three pilots on the flight deck.

Excerpt from the transcript:

> Okay….we were climbing up through, I think, yes, 12,000 feet … on our way back to [deleted], when the left engine literally exploded …. Well, I guess the, the initial reaction is you go into a, oh shit factor, I suppose …. That's a startle, a startle factor, I suppose … My first observation was then, within a couple of seconds, was the oil pressure low lights came on, when the oil pressure dropped to zero….So I shouted something like "engine failure, oil pressure zero", something like that….Yes. A huge startle factor … Such … what surprised, what surprised me and the others was that you go in, go into, immediately, this mode of, that you learned in the simulator where, you know, you've got to do something.

Analysis

This event was described earlier by one of the other pilots on the flight deck. The account is interesting in that there is some variation in the events with a slightly more positive interpretation of what ensued following the failure. It also describes some significant PTSD which lingered for some time after the event.

As the engine disintegrated substantial aural, visual and somatosensory stimuli induced a strong startle in all three pilots. In this account the pilot concerned felt some short delay in being able to process what was happening. This was described as only a couple of seconds; however, it may be that an element of temporal distortion was in effect.

Following the startle, the pilot described being relatively unaffected and when quizzed during the interview about the events that followed, failed to recall that one of the critical elements in the severe damage checklist memory items was inadvertently omitted. This point was discussed at length, however he did not recall that the engine fire handle had not been pulled as part of the initial shutdown drills and that it was only accomplished during the follow-up checklist. This is very interesting in that the startle may have created some cognitive disruption which disrupted memory of the events. It appears that recall of some details during the traumatic event was distorted slightly in the pilot's memory. This is common (e.g., Cambridge, 1997; Halligan, Michael, Clark, & Ehlers, 2003; Wright & Livingstone-Raper, 2002) following a traumatic incident. The pilot concerned also reported some strong PTSD symptoms for some time after the event. He described being very jittery on a flight four days later, jumping at the slightest noise.

Determination of Pathological Behaviour

The behaviours exhibited by the pilot concerned are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 24b

Pilot Froze After Bounced Landing

Synopsis

During a practice flight prior to a commercial licence flight test, a pilot in a light twin made a very poor landing which resulted in a large bounce. When the aircraft bounced approximately

20 feet into the air, the flying pilot took no action, and the aircraft pitched violently down (possibly having stalled), striking the ground in an uncontrolled manner and damaging the right propeller. It bounced once again but only slightly and subsequently was recovered as the aircraft settled onto the ground. The pilot appeared to make no control inputs at all from the time of the first impact and appeared frozen and staring blankly out the window. The interviewee was in the back seat, acting as an observer and was unable to take control.

Excerpt from the transcript:

> Anyway, it was actually a three-wheel touchdown, so flat landing, and then it kind of bounced up and that's … the pilot flying was totally, you know, frozen, did absolutely nothing, and that's when the aircraft does the usual phugoid where he came down, clipping the right prop on the runway, and then came back up again … That, you know, I didn't say anything because he's going to hopefully recover and probably I was in a panic as well because I didn't expect that. So I didn't expect sitting, me sitting in the back … after the big bounce, the windscreen was pretty much filled up with the runway and that's, you know … and probably I was panicked as well, you know, to be honest, but probably the pilot was totally panicked.

Analysis

This was a case where the pilot was badly startled and then failed to take any appropriate action. There was clearly some significant cognitive disruption brought on by the suddenly presented critical situation, engendering a severe acute stress reaction. The lack of action is symptomatic of a WM devoid of constructive ideas, and probably filled rather with anxious thoughts. It appears that the pilot concerned was unable to implement any sort of recovery plan, and his demeanour was typical of a mind bereft of action schemas. This was a potentially fatal accident and it was fortuitous that the aircraft had not bounced any higher.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 25b

Failed to Manage Flight Path After Autopilot Dropped Out

Synopsis

On departure at night in a jet aircraft the first officer engaged the autopilot at approximately 500 feet. Passing approximately 1,000 feet, the autopilot disengaged for an unknown reason but the first officer took no action to either control the aircraft or to re-engage the autopilot. The aircraft started a shallow, turning descent with no action from the PF. The captain recognised that the first officer had possibly become incapacitated by acute stress and made a suggestion to engage a lateral tracking mode (Heading Select). The first officer took several seconds to react but then engaged Heading Select. The captain then suggested engaging a vertical mode, followed by the autopilot. The first officer once again reacted slowly but complied. He remained disengaged for some time afterwards.

Excerpt from the transcript:

> So I didn’t get any feedback; I looked [at the first officer], you know, I could see his arm was very, very tense, very tight; strong holding on the control column, but his eyes were kind of, were moving; not verbalising anything … He’s obviously in one of those, you know, tense, can we say … how can we say—balloons, tension balloon; he’s just totally overwhelmed and consumed by the, everything that had finally caught up with him ... so were heading back so I turned around, pointed in the right direction that I wanted the plane to go and I said to him, “Oh, look at that Heading Select’s available.” …. So I just waited for … you know, it was probably a few seconds in the air and then

> just gingerly his little right hand comes up and he pushes Heading Select, so I, I'm getting some feedback now from him … So once that was going I said, "Oh, look, the level change is available", so now he had flight director and he's kind of bringing it back up, following the flight director. I said, "Oh", you know, "auto-pilot's available" and sure enough, his little hand comes up, pushes the auto-pilot ….
> And, you know, then we got the track and, you know, he started sort of verbalising. But even the verbalising was, I would say a little bit … if I have to put a word to it—it was slow … laboured … like, in all consciousness, hadn't quite arrived at that stage. By the time we got to top of climb he was switched on totally, full consciousness was back, was back on board and I thought, oh, good, we're going to have a good arrival.

Analysis

This was a situation where there was an unexpected disengaging of the autopilot, and the pilot concerned suffered some cognitive disruption as a result. The fact that the first officer responded to the captain's suggestions, albeit slowly, indicates that there was still some cognitive capacity available for comprehension, but the laboured nature of his reactions suggests that cognitive impairment was significant.

This incident was a case where an undesired aircraft state developed reasonably quickly as the PF became overwhelmed by a simple autopilot failure, and had the captain not intervened, then the situation could have deteriorated rapidly as the aircraft rate of descent increased in close proximity to the ground.

The behavioural inaction, followed by a very slow and laboured reaction to instructions (suggestions) was suggestive of severe cognitive impairment after being overwhelmed by acute stress. It is likely that the first officer was experiencing significant levels of arousal and did not fully regain his composure until some time after the event.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, there was no action taken at a time when action was warranted and/or expected.

Event 26b

Pilot Froze During Instrument Failure

Synopsis

During descent, at night and during a snow shower, with the captain flying, the captain's airspeed indicator suddenly indicated a significant speed drop, followed by the stick-shaker activating. The captain pitched the aircraft about five to eight degrees nose down to try and recover the speed. He then suspected a failure of his primary speed indications and checked his standby instruments, which indicated speed significantly higher than on his primary instruments and approaching the maximum allowable. He recovered the aircraft using the standby instruments. The first officer took no part in the diagnosis or recovery from the failure, with the captain describing his contribution as a "void". He appeared to be badly startled and incapable of contributing to the diagnosis or recovery from the malfunction and ensuing undesired aircraft state.

Excerpt from the transcript:

> … at no point did the first officer indicate there was anything abnormal. So, basically the first officer was [unclear] pitch the nose down following my airspeed reduction, probably about five or eight degrees. At that point my airspeed was still reducing so [unclear] to increase rapidly and there was no comment from him at all … before I looked across at what was going on and then responded to it and just this void—nothing on the right hand side.

Analysis

In this case, while descending in icing conditions over mountainous terrain, the captain's airspeed indication system suddenly suffered a partial blockage which led to a rapid reduction in indicated airspeed. The stall warning activated as a result and the experienced captain then lowered the nose to try and regain the airspeed. As this was being done he noticed a significant discrepancy between his ASI (Airspeed Indicator) and the standby ASI, and so suspected an instrument failure. The standby ASI was then compared to the first officer's ASI and found to be far more accurate. Pitch attitude was returned to normal and the flight was continued using the standby ASI. An overspeed of approximately 15 knots had occurred during the pitch down. The experienced captain was fortunately capable enough to recognise the problem and rapidly took measures to restore the aircraft to a stable descent, but not before inducing an undesired aircraft state. The fact that he recovered very quickly was testimony to his situational awareness and it was very fortunate that he did not continue to chase the speed on his primary display before the situation became irrecoverable.

The first officer appears to have been badly startled by the sudden pitch down and stick-shaker stall warning. He took no part for some time thereafter, and was totally unresponsive as the critical event unfolded. It is likely that the first officer suffered considerable cognitive disruption following the startle and entered a high state of arousal. His behavioural inaction allowed the aircraft to exceed the aircraft's maximum speed by a considerable margin, a potentially damaging situation which could have had disastrous effects had it continued.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 27b

Mishandled Automation on Approach

Synopsis

While turning onto final approach the experienced captain mismanaged the aircraft's automation, leading to a rapid reduction in airspeed which was not recognised or corrected for. He had attempted to fly in a VS mode (at 100fpm down) to intercept the ILS glideslope, however the capture never occurred and the aircraft continued to get higher and higher on slope, while the aircraft speed was not recovered by the autothrottle and decayed rapidly. A C&T captain who was in the right seat was forced to take control as the speed decreased to a dangerous level, by applying full thrust and disengaging the autopilot, followed by a pitch down. The captain seemed stunned by the whole process but resumed control once C&T captain had regained control and placed the aircraft back on the correct profile at an appropriate speed.

Excerpt from the transcript:

> And he didn't respond, he didn't do anything so I looked at him, I said, you know, "speed" and by this time we're Vref minus five. And, I got it, I got it and then did nothing except close the [unclear] still on about a hundred feet a minute. Were going high on the profile, speed then comes back, again, to below V ref, V ref minus, probably about minus eight at which point I disengaged the autopilot, pitched the nose forward and said I have control … and looked across at him and said what just happened? And he went, what mode did I have it in? I said well VS at a hundred feet a minute, and he went the autopilot didn't respond. I went, no … Again, we've got a guy, you know, looking at the instruments, fully aware, lovely clear day, fully aware of everything that was going on and then being told by the airspeed indicator that his speed was, you know, dangerously slow and reducing, but he didn't react …

Analysis

This was an event where a very experienced captain mismanaged the aircraft automation to the point where an undesired aircraft state developed very rapidly and wasn't corrected. It was only intervention from a check captain in the right seat that prevented the aircraft from receiving a stall warning. For some reason the autothrottle had not corrected the decreasing speed, and as the aircraft, in a fully configured state, with minimum thrust and a commanded vertical speed of just 100fpm, rapidly slowed to below Vref (final approach speed).

In this case the captain seemed suddenly overwhelmed by a rapid deterioration in the course of events. There appears to have been a breakdown in cognitive processing which in turn developed into a lack of situational awareness. This was possibly borne out of a conditioned expectation that the automation would work correctly and that therefore the speed would be managed effectively by the autothrottle.

The behavioural inaction displayed by the captain may have been due to elevated arousal levels as the situation rapidly deteriorated. His expectation would have been that the aircraft would intercept the ILS Glidepath and descend on a 3° slope, with the speed being managed autonomously by the autothrottle. When the aircraft failed to capture the Glideslope and instead continued above the desired path due to the 100fpm selected Vertical Speed, he became completely incapable of integrating the information presented to him and then forming an action schema to rectify the deteriorating state.

Had the C&T captain not intervened, or had there been a less assertive first officer in the right seat, this undesired aircraft state could easily have developed into a considerably worse situation, with potential impact on flight safety.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following information.

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.

- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in working memory function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, there was no action taken at a time when action was warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, to the point where another pilot was forced to take control.

Event 28b

Engine Failure

Synopsis

On climb out passing approximately 3,000 feet in a light twin, the left engine's crankshaft sheared, resulting in the left propeller windmilling. After a short period of disbelief and calculation, the decision was made to shut the engine down and to return to the departure airport. The return was normal and the remainder of the flight was uneventful.

Excerpt from the transcript:

> I think I didn't believe it until I looked at the instruments, it was only a few seconds really, but it seemed like an eternity, you know. So yes, I just remember, I will just sort of reiterate it I suppose, just looking outside and not, well, trying to make myself, I suppose, not believe what I was seeing, you know? I was in denial about, "no, that's not right."

Analysis

In this case there was a failure of the crankshaft in the left engine resulting in the left propeller windmilling in an unfeathered state, creating substantial drag. The propeller was finally feathered and the engine secured after some delay.

The pilot, who was relatively experienced in light twins, reported feeling relatively calm, however he failed to accept the information being presented to him for several seconds. He continued to look outside at the windmilling propeller, unable to correlate the environmental cues with his mental schema of what was happening. He appears to have been confused by the rotation of the propeller (in its unfeathered state) and failed initially to attribute it to an engine failure. It wasn't until he looked inside that he saw the engine instruments indicating a failure and he was only then able to establish that a failure had occurred. Once the failure had been positively identified, he was then able to carry out the shutdown and return to departure port without too much further cognitive disruption.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 29b

Incapacitation

Synopsis

About half an hour into a simulator detail one of the pilots suffered a seizure. The other operating pilot felt suddenly overwhelmed by the situation and was totally unsure what to do. The simulator instructor eventually called an ambulance, but was unsure what to do.

Excerpt from the transcript:

> … there was a noticeable period where, you're sort of, not floundering around thinking of something to do, but you just trying to get your head to that point in the game, I know there's something I should be doing here, what should I be doing? ... sort of startling, and there was actually just a noticeable period, now that you are talking about the startled thing, of, well, I actually don't know what to do here, I should be doing something, I should be helping, but I can't think what I need to do to be helping. And then, I just remember it sort of popped into my head, in fact that I was talking to the instructor as well afterwards, and [unclear] the ambulance, he said he went through the same thing, like, "what's that first aid thing that we use …"

Analysis

This incident was uncommon in that it involved an unexpected and sudden medical event involving a pilot. The captain was performing some routine setup tasks while the simulator instructor had his attention diverted to setting up the simulator for the next exercise. The captain then noticed the first officer starting to fit and received a strong startle in the process. Following this startle the captain was completely unsure about what to do for a short period and it was only when he brought it to the attention of the simulator instructor that a decision to call for an ambulance was made. No attempt had been made in the intervening time to try and move the first officer into a recovery position, an omission which could have resulted in the first officer swallowing his tongue or suffering another injury.

In this case the captain admitted to feeling startled and then became confused about what to do for some time afterwards. His confusion was typical of the cognitive disruption often experienced after startle and his impairment in deciding what to do was potentially life-threatening for the first officer. The lack of expectation for such an event, coupled with no pre-conceived action schema for what to do if it ever did happen, contributed to a bewildered state.

Pilot incapacitations are practised in the simulator; however, they are invariably carefully orchestrated and semi-expected, with the "incapacitated" pilot simply failing to respond during an approach or on departure. This conditioned expectation for what an incapacitation is may have contributed to the lack of action plan when faced with a real-life situation which was dissimilar to previous iterations.

The cognitive impairment of the captain following the startle could have contributed to a negative outcome had time been critical.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural and visual modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 30b

Engine Failure During Raw Data ILS Go-Around

Synopsis

While on a simulator check flight the crew were given an unannounced change of detail from that previously briefed. They were told that due to the presence of a regulatory inspector on board, they would take off, do some upper air handling work and then return for an ILS approach before continuing with the pre-briefed scenario.

During some steep turns the instructor failed the flight director and autopilot on the captain, requiring the remaining steep turns and the approach to be completed “raw data” (without autopilot and flight director guidance). The captain then flew the unexpected raw data ILS but became unstable as the aircraft approached DA and elected to go around. During the go-around the simulator instructor then failed one engine, necessitating a single-engine, raw data missed approach. The captain felt somewhat overwhelmed but managed the go-around and clean up as well as he could, but the first officer said nothing throughout the missed approach and appeared to be frozen.

Excerpt from the transcript:

> … I got to DA and decided I would execute a go-around, which is the right thing to do … to find that, as I pushed the TOGA button, I still had no guidance. It was now ruled out then, missed approach as well. On top of that, the aircraft is not gaining altitude and was sinking to the point that "don't sink, don't sink" came up ... Oh, great. A raw data go-around with an engine failure … Yes, and then I was ... I was shocked. I was shocked. And it didn't take long for the brain to be on the blink, basically … And [the first officer] … didn't say a word and he never even said a word until we'd cleaned up, and that flight freeze and he still hadn't said a word. He was just totally overwhelmed…

Analysis

The captain in this exercise was extremely experienced; however, the simulator instructor introduced a combination of unbriefed and unexpected failures, which combined to test the crew to their limits.

The captain had initially been given a low-visibility take-off with a crosswind, just one knot under the maximum aircraft limit. This was a highly challenging and unrealistic scenario which created a high level of arousal in both the captain and first officer. Similarly, the failures of both the autopilot and flight director, requiring steep turns to be conducted raw data, was a very challenging exercise which continued to maintain a high level of arousal. During the raw data ILS approach, the captain, who had not expected this, became slightly unstable as he approached DA and made a sound decision to go around, however the simulator instructor then chose to introduce an engine failure as the go-around was commenced. This created considerable control difficulties and the unexpectedness of both the go-around and the failure, coupled with the criticality of the situation, created an overwhelming mental load on both the pilots. The captain managed to control the aircraft as well as could be expected, but the first officer was unable to participate further other than to raise the landing gear and flaps under instruction.

The fairness of this assessed exercise (especially in the presence of a regulatory evaluator) is questionable, but this point is beyond the scope of this analysis. It is fair to say that the level of arousal experienced by the captain throughout the exercise was very high and he struggled to maintain situational awareness while his remaining brain capacity was continually taxed to its limit. The captain described being “shocked” by the engine failure during the go-around, and it is likely that he suffered some cognitive impairment as a result. Startle has been shown to be exacerbated when experienced during a high state of both arousal and concentration (Simons, 1996), so it is highly likely that the tactile and visual realisation of another failure during the go-around, coupled with a “don’t sink” warning, would have contributed to a strong startle. The deleterious effects of this on subsequent psychomotor and cognitive performance are likely to have contributed to problems experienced in maintaining an accurate flight path during the missed approach.

The first officer, who was not expecting a go-around or an engine failure, appears to have been overcome by a strong startle and persistently high levels of arousal. This apparently contributed to a period of behavioural inaction when he was incapable of performing any of his normal support duties other than to raise the landing gear and flap levers when ordered to. While the cognitive load on the captain must have been immense, it appears that the first officer was severely affected by over-arousal and was overwhelmed to the point of inaction.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent for a significant period of time.

Event 31b

Failure to Cancel Cabin Altitude Warning

Synopsis

This event involved a series of typical behaviours observed over a period of months rather than a single specific event. It was described by a C&T captain who had observed this type of behaviour on several occasions during simulator exercises. He described several occasions where pilots failed to respond appropriately to an automated cabin altitude warning following a rapid depressurisation simulation exercise. During this particular exercise the C&T captain induces some sort of failure which causes the cabin pressurisation to be lost rapidly. When the cabin altitude climbs through 10,000ft, a continuous "beep, beep, beep…" warning sounds. This warning can be cancelled simply by pushing a "horn cancel" button on the overhead panel, however on a number of occasions this simply wasn't done and the very intrusive warning sound was left to run continuously for some considerable time.

Excerpt from the transcript:

> And all of a sudden, you shut that off and you don't hear or heed anything. You're just so focused and you see this happening often, even though you're briefed and said you know exactly where that button is, you know … The button is right there, next to the controller, and when you hear that noise—beep beep beep—that's when you push the button, and so on and so forth. Yes … over a six month period, to find a handful who just sit there, kind of oblivious for at least a minute. Totally oblivious …

Analysis

The behaviour described here relates to the failure of pilots to cancel the cabin altitude warning horn when a rapid depressurisation exercise is conducted in the simulator. The C&T captain described observing several pilots who had suddenly been presented with an audible warning informing them of a critical event. It would be unusual in a simulator exercise for this to be totally unexpected; but the timing of the emergency onset would be unknown, generating an element of surprise.

The emergency (cabin high altitude) would generally be alerted in the simulator by the activation of the cabin high altitude alert (a continuous beep-beep-beep …). One of the first actions in any emergency is to cancel the audible warning as it is generally acknowledged as being intrusive while trying to analyse the problem at hand.

In the cases described, individuals failed to cancel this warning, leaving it beeping for up to a minute, probably due to the sudden onset of elevated arousal levels as they are presented with a threatening stimulus (Gasaway, 2012; Staal, 2004). This is likely to be an attentional channelling issue as the brain re-prioritises the attentional resources towards visual and tactile cues, at the expense of auditory stimuli. It is not until the level of arousal decreases slightly that some WM function can be reassigned to the intrusive auditory stimulus and some action schema can be generated to remove the annoying noise.

This is a form of behavioural inaction, but is initiated by a startling stimulus. The action of cancelling the warning is not carried out due to overwhelming stressors which hijack the attentional resources of the working memory. This phenomenon is similar to an incident discussed below in which the fire bell was not silenced after takeoff.

Determination of Pathological Behaviour

The representative behaviours exhibited by the various captains and first officers observed are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.

- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent for a significant period of time.

Event 32b

Engine Failure

Synopsis

During ab-initio training in a single-engined aircraft, an instructor and student were returning to the airfield at 3,000 feet when the engine coughed and then stopped. The instructor, who had suffered a similar failure before, assumed control and commenced a controlled descent to the airport. Approaching the airport some power was restored to the engine and a successful approach and landing was conducted. When the engine initially stopped the student was badly startled and let out a scream. He took little part in the flight thereafter.

Excerpt from the transcript:

> … as we were just about 3000 feet, the runway off the nose, the engine coughed a couple of times and then pretty much stopped … and the student was quite surprised, let out a bit of a scream … Yes, he screamed pretty loudly. Yes, he was pretty startled, shaking a little bit as well. I said look, mate, don't worry about it, [the airfield is] still there, we can easily make that … he was just sitting there.

Analysis

In this case, the instructor and student were suddenly presented with a threatening, unexpected critical event. The instructor—who had suffered a similar event previously—was initially startled, but quickly assumed control and managed the power-off arrival to the proximal airport well. The student, who had little experience, was very badly startled and let out a scream. This was indicative of very high levels of arousal and it appears his cognitive function was badly affected thereafter, as he had little input into the remainder of proceedings.

This would have been an interesting incident had the student been solo. He was clearly badly affected and had the more experienced instructor not been on board to take control the outcome could have been less favourable.

Determination of Pathological Behaviour

The behaviours exhibited by the student are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 33b

Froze During Spin Recovery

Synopsis

A series of exercises were being done with military flying instructors, teaching them how to recover from high-rotational spins. During one such spinning exercise the pilot flying, who was an experienced instructor, froze on the controls and took no action to exit the spin. The instructor with him had to physically hit him to make him relinquish his grip on the controls so that he could recover. The recovery was finally completed below the minimum bailout altitude.

Excerpt from the transcript:

> …. I looked at him and he wasn't responding and my plainest thought was he's having a [communication] failure so I said "recover now" and he said nothing and he just hung on to the controls. So I took over control and attempted to recover but he was holding on with a grip of steel … And the aircraft was moving like there was no tomorrow and I basically had to whack him across the … chest with my right arm. He still didn't let go but it sort of sufficiently disturbed him so I could get on to start moving the pole forward and the aircraft recovered …

Analysis

This was likely a case of behavioural inaction; the PF simply froze on the controls. As the aircraft entered an induced high-rotational spin, it appears that the PF suddenly experienced very high levels of arousal and became overwhelmed. This manifested itself as a physical lock-down, with an iron grip on the controls. It is highly likely that the PF's cognitive state had become suddenly impaired by the acutely stressful, threatening situation which presented itself. This was despite a successful iteration and recovery from the same exercise immediately prior to this one, albeit that the previous exercise had a slightly gentler entry to the spin.

It is extremely fortuitous that the senior instructor was able to physically regain control. Recovery was actually made slightly below the bailout altitude and had recovery not been made when it was then it is likely that the consequences could have been severe. In this incident it appears that the only reason situation outcome was positive was because the senior instructor attempted physical violence to wrest control, very close to bailout altitude.

Determination of Pathological Behaviour

The behaviours exhibited by the PF are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, no action was taken when warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, to the point where another pilot was forced to take control.
- A pilot physically froze on the controls to the point where some physical action was necessary by another pilot to wrestle control.

Event 34b

Low Level Bird Strike Through Windscreen

Synopsis

While on a very low-level operation at approximately 140-150 knots, a light twin-engined aircraft suffered a major birdstrike. The eagle shattered the windscreen and the sole pilot suffered moderate injuries. Following the impact the pilot's attention remained temporarily fixed on the navigation, rather than on the emergency, before he eventually pulled up to a safe altitude. The aircraft was recovered to a nearby airfield without further incident for a well-managed landing.

Excerpt from the transcript:

> And it took me a few seconds to realise what had happened, absorb the whole thing and I suddenly pulled the plane up to a safer altitude. And then I came up with different strategies on how to deal with it. But that was my initial reaction at that stage …

Analysis

This incident was potentially catastrophic. The pilot was on a very low-level mission at approximately 100 feet AGL when the windscreen disintegrated following a collision with a large eagle. The pilot, who had been concentrating intensely on the task at hand prior to the impact, described a period of a few seconds before it occurred to him what had happened, and wasn't aware that he had been injured during the incident.

It is likely that the pilot was confronted with a very significant startling stimulus, as the quiet, peaceful cockpit was suddenly transformed into a cacophony of noise and 150kt gale and it is highly likely that an extremely high level of arousal was initially experienced. The cognitive disruption following the startle, perhaps in concert with the unconscious denial, caused a period of slow reaction before the integration of the environmental cues into perception allowed sense to be made of what had happened.

Once the pilot regained his wits, some semblance of criticality was prioritised and he pulled back on the controls to gain some height. Once he levelled the aircraft at 300-400 feet, he was able to take better stock of his predicament and tried to manage the damage, which was serious. He then had the cognisance to alert his company to the emergency and proceeded to a nearby airfield where he landed without incident.

This incident was a critical emergency which had a sudden onset and life-threatening consequences. Following an initial period of surprise, the pilot slowly gathered his thoughts and made sense of the situation. It appears that his recovery from the initial startle was quite rapid and he recovered the situation well thereafter.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 35b (Synopsis only supplied)

Engine Fire after T/O – Pilot Froze

Synopsis

This event happened during a simulator assessment exercise which was being conducted for two pilots who were seeking flying positions in a new company. The exercise involved one candidate being assessed for a captain's position sitting in the left seat, with the other candidate being assessed for a first officer's position sitting in the right seat. The company check captain was sitting in the centre seat, running the simulator and conducting the assessment.

The exercise had been briefed as a series of upper air exercises followed by a return to the departure airport for two instrument approaches. As an interview ride, generally the expectation is that it will be a simple handling exercise, designed to demonstrate basic instrument flying and management skills, so the expectation from both pilots was that it would be conducted on two engines throughout.

The exercise commenced with a normal start and taxi out followed by a take-off. The take-off was normal until the aircraft became airborne, at which point the first officer (PM) called "positive rate" which was followed by a call for "gear up" from the PF. As soon as the first officer had initiated the gear retraction, however, there was a sudden and unexpected engine fire warning, which consisted of a red light and a very loud bell. Having had a mild sense of suspicion for any eventuality in the simulator, the captain (PF) wasn't too surprised, but the first officer jumped severely and then went very quiet. The normal first response from the PM would be to cancel the warning, which would also cancel the fire bell. This is standard practice because the fire bell is very intrusive and it is hard to think while it is ringing. However, the first officer did nothing. When the captain looked over at him, the first officer was just staring straight ahead, so the captain said "cancel the warning thanks", however this had no effect. As the aircraft was by then at acceleration altitude the PF reached up and cancelled the warning himself. He then called for the memory items for the engine fire, to which the first officer did nothing. The captain then shouted at him "are you with me [name deleted]". This had some effect and he looked back and nodded, so once again the memory items for the engine fire were asked for. From there on he returned somewhat to normal and carried out the memory items, albeit slowly, followed by the aircraft clean up and checklists as per SOPs. By the time all these items were completed, he seemed to have returned to normal and the remainder of the exercise proceeded well.

When asked about it afterwards, the first officer simply apologised and said he had been really surprised by the fire warning for a moment. His performance during the remainder of the simulator session was fine, but he was definitely frozen for a short time following the fire bell.

Analysis

This was a case where one pilot was very surprised by both a visual and auditory stimulus (engine fire warning and bell). This appeared to induce a very strong startle, which induced a period of behavioural inaction. The PM failed to react to the call to cancel the fire bell and was reported to be simply “staring straight ahead”. The failure to respond to the first two calls from the captain was indicative of some severe disruption to cognitive processes, which likely came about as a reaction to the strong startle. The behavioural inaction was indicative of a very high level of arousal, which had probably resulted in an acute stress reaction which had overwhelmed the first officer’s working memory.

This was a situation in which a strong startle, followed by a period of behavioural inaction incapacitated a pilot for a period of some 10-15 seconds. In this case there was no significant undesired aircraft state and no impact on situation outcome, however, the potential existed had the captain also suffered some startle effects. It is also conceivable that any delay in actioning the engine fire checklist could have increased the likelihood of the simulated engine fire becoming uncontrollable, which could have had significant consequences for flight safety in a real-life situation.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural and visual modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 36b (Synopsis Only Provided)

Engine Failure on Takeoff

Synopsis

Following a takeoff in a light twin, a relatively inexperienced pilot suffered a sudden and total engine failure on one engine. After a short delay he carried out the appropriate shutdown drills and attempted to climb away, but his perception was that the aircraft was descending (despite not checking the vertical speed indicator) and he elected to land instead in a paddock in front of the aircraft. On approach to the field he lowered the landing gear and selected half flap, however this was done too late for the gear to fully extend and the aircraft landed with the wheels up. Following the gear-up landing when the aircraft came to a halt ,he failed to secure the aircraft and evacuate either himself or his passengers, instead sitting motionless for some thirty seconds before taking any action.

Excerpt from the synopsis provided:

> I thought I was ready for it, but I was definitely startled. I remember thinking that this can't be happening to me, and it took a few seconds to realise that it was indeed happening, and I'd better deal with the situation right away. So I launched into my previously-rehearsed engine failure after takeoff (EFATO) drills and, for the first time in my life, experienced the "swimming in glue" syndrome I'd read about…everything seemed to be happening in slow motion … I remember a loud horn sounding during the flare. The horn turned out to be the gear unsafe warning, but I didn't realise it at that

> moment (not that there would have been any time to do anything about it) … There was something a bit odd about the landing, but I didn't realise until later that the gear was still up.

Analysis

This was clearly a sudden and unexpected critical event. While the pilot said that he had been prepared for an engine failure and had even rehearsed the engine failure drills, the failure clearly induced a significant level of startle. This was followed by a few seconds of disbelief. It is unclear whether this momentary delay had any subsequent impact on the outcome; however, it is conceivable that had full power been applied a few seconds earlier than perhaps the aircraft would have climbed sufficiently for the pilot to assess that he would clear the gently rising terrain.

The startle was also followed by some cognitive impairment (the analogy of "swimming in glue" was described by the pilot), however it appears that recent mental rehearsal of the failure drills prior to takeoff, facilitated adequate recall of the engine failure drills, albeit somewhat slower than normal. Some question also remains, from the accident investigation, about whether the pilot's perception of the aircraft descending was accurate, or whether this was a misperception which was accentuated by the cognitive impairment following startle or the acute stress which clearly prevailed. The fact that the gear hadn't been fully lowered prior to the landing, and that the pilot was unaware of its status, also strongly supports the suggested cognitive disruption theory, post-startle, and with very elevated arousal levels.

Investigators suggested afterwards that given the weight and conditions at the time, the aircraft should have been capable of climbing at 150 feet per minute. Research has shown some psychomotor impairment is common following startle (e.g., Thackray, 1988), so it is conceivable that slight inaccuracy in flying the exact speed with the optimum bank and slip could have contributed to the lack of performance perceived by the pilot.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Event 37b

Engine Fire on Takeoff (Synopsis only supplied)

Synopsis

On a fine day, during the third takeoff of a six sector day, a 19-seat twin-engined commuter aircraft was rotated as normal with the captain as the PF. As the aircraft left the ground the PF called for “gear up” as the aircraft was clear of the runway. The first officer raised the gear handle and then responded with “engine fire”. This particular aircraft type is not fitted with a fire bell to indicate an engine fire warning, so the only indication was a fire light, placed prominently in the upper central instrument panel.

The PF, who had not seen the light until it was announced, was very surprised by this revelation and simply stared at the light for a period of 3-4 seconds, before asking the first officer “what did you do?” The first officer simply said “nothing” as the aircraft continued to climb away with the unextinguished engine fire.

After another 3-4 seconds the PF finally gained enough wherewithall to realise that this was a real engine fire and called for the memory items for the engine fire drill, while at the same time accelerating the aircraft to the flap retract speed. Once the memory items for the fire drill were completed, the flaps were retracted and the aircraft continued climb to 1500 ft.

A PAN call was declared with ATC and a clearance was obtained to re-circuit for an approach to the departure runway. From there, appropriate calls, checklists and PAs were made, while the aircraft extended slightly downwind before returning via a visual approach for a textbook landing.

The concern was the estimated 6-8 seconds following the fire announcement by the first officer when no action was taken by the captain. The overriding thought during this time was described as: “that can’t be real … that can’t be real … what did you do? ....”.

Analysis

This was a case where a sudden, unexpected emergency created a strong startle, which induced an overwhelming acute stress response. The PF was suddenly confronted with a life-threatening situation and went through a mental process of disbelief, denying the existence of the stressor for several seconds until the reality of the situation entered consciousness.

In this incident it was fortuitous that the delay in actioning the engine shutdown and firing of the extinguisher did not result in a rapidly deteriorating situation with a negative outcome.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural and visual modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

- A surprising stimulus is followed by a period of inactivity when an immediate or timely response was warranted.
- There were actions consistent with significant confusion, breakdowns in cognition, situational awareness, or poor decision-making evident.

Table 8 lists the accidents and incidents in this section in which the phenomena of startle, freeze or denial were identified.

Event	**Flight**	**Phenomena Observed**
1b	Engine fire – forgot memory drills	Startle
2b	Unextinguished engine fire	Startle
3b	Bird strike on take-off – slow to reject	Behavioural inaction
4b	Catastrophic engine failure (same event as 24b)	Startle
5b	Froze on approach and descended below glideslope	Behavioural inaction
6b	Engine failure after take-off in a single engine aircraft	Startle
7b	Flaps retracted instead of gear after take-off	Startle
8b	Hijack	Startle, behavioural inaction
9b	Engine failure in the cruise	Startle
10b	Engine shutdown in the cruise	Startle
11b	Ejected immediately prior to terrain impact	Denial
12b	Fuel control problem caused engine malfunction	Startle
13b	Depressurisation	Startle
14b	Engine shutdown due oil leak on departure	Startle
15b	Engine runaway requiring shutdown	Startle
16b	Rejected take-off due to lack of performance	Behavioural inaction
17b	GPWS warning at night on departure	Startle
18b	Landing gear failed to lower	Startle
19b	Near miss with MD-11	Startle
20b	Unstable—preoccupation with close proximity traffic	Behavioural inaction

21b	GPWS warning in cloud during approach	Startle
22b	Speed decay caused unexpected stick shaker	Startle
23b	Catastrophic engine failure (same event as 4b)	Startle
24b	Aircraft bounced badly on landing	Startle
25b	Autopilot disengagement led to UAS after T/O	Behavioural inaction
26b	During unreliable airspeed event FO did nothing	Behavioural inaction
27b	Mismanaged automation caused unstable approach	Behavioural inaction
28b	Engine shutdown on departure	Startle
29b	First officer incapacitated	Startle
30b	Unexpected single engine go around in simulator	Startle
31b	Depressurisation exercise in simulator (representative)	Startle
32b	Engine failure during training exercise	Startle
33b	Pilot froze during spin recovery exercise	Behavioural inaction
34b	Bird strike at very low level	Startle
35b	Simulated engine fire after take-off – FO froze	Startle
36b	Engine failure on take-off	Startle
37b	Engine fire warning at rotate	Startle

Table 8 Event Database - Research Interviews

5.3 Discussion

The research interviews revealed some interesting behaviours amongst pilots who had experienced critical events. Of the 37 events covered, 28 included iterations of a startling stimulus being encountered which then had varying effects on performance. Additionally, nine of the incidents indicated elements of behavioural inaction and one indicated the likelihood of denial-type processes. One incident, the hijacking case, indicated an element of behavioural inaction from the first officer, while the captain’s behaviours were more likely to have been associated with a startle; as a result 37 events were considered but 38 pilot behaviours were examined and attributed.

As with the accidents from the case studies in chapter 4, some behaviours following a startling stimulus were typical of behavioural inaction or denial. Events such as the engine fire where the captain forgot the memory drills (1b), the GPWS warning at night (17b) and on approach (21b), and the simulated engine failure where the first officer froze, were cases in which the pilots should have taken some action straight away but were incapable of doing so. In these cases and in others, it appears that the onset of the sudden surprising stimulus created substantial cognitive disruption, which resulted in ineffective or even inactive behaviours. These were attributed to a startle due to the sudden onset of the stimulus, as opposed to those incidents which gradually or steadily develop into a critical event, such as the lack of performance on takeoff (16b), the preoccupation with traffic (20b), the bounced landing (24b), or the spin recovery (33b). In these cases, there was no sudden startling stimulus, and the situation which engendered an acute stress response developed over a period of time.

Two of the behavioural inaction incidents were very serious, and only intervention or luck prevented them turning into accidents. The case in which the captain froze on the controls during an instrument approach in cloud (5b) was almost catastrophic, and it was very fortunate that the aircraft broke clear of cloud in time for the captain to mentally recover and to then take recovery action. Similarly, the pilot who froze during high rotational spins (33b) may well have faced a catastrophic situation had his instructor not intervened with a physical blow to the chest. The iron grip the pilots in both of these incidents displayed was indicative of a major disruption in their cognitive processing, to the point that they were unable to recover by themselves for some time. These were very serious incidents in which behavioural inaction was very evident. While several pilots reported a brief period of "disbelief" following a startling stimulus, this was attributed to cognitive disruption following startle rather than to denial type processes. Unlike a situation where the pilot faced a deteriorating and acutely stressful situation with which they were unable to cope, and therefore needed to employ a stress relief mechanism such as denial, the period of disbelief following a surprising stimulus was considered to be a normal response in which a person tried to rapidly make sense of the environmental cues while suffering some temporary impairment in information processing brought on by the startle.

Two incidents were attributed to denial. These were the low-level ejection (11b) and the engine failure on departure (28b). Both of these events were classified as denial predominantly on the basis of self-report from the pilots. There may have been some bias in their assessment of denial as causal, rather than startle, however their self-reporting of strong denial met the criteria for classification as such. These incidents may well have had some element of startle which was not perceived by the pilots concerned, and therefore their enduring memory is rather one of denying the stressor rather than simply being surprised. Some argument could be made either way for startle or denial, based on the criteria set in the analyses, however the conviction of the intense, self-reported denial warranted its inclusion as a denial-type behaviour.

While the majority of the incidents discussed in these case studies resulted in positive outcomes, there were instances of undesired aircraft states which could have led to further deterioration of the situation and a negative outcome. It is likely that each of the incidents involved behaviours which were pathological, although recovery from these conditions allowed the situation to be rescued in most cases without a negative outcome.

Chapter 6 FLIGHT SIMULATOR STARTLE EXPERIMENT

6.1 Methodology

Simulator experiments using 18 participants were conducted at the Boeing Flight Training Simulator Centre in Brisbane over May and June 2012. The simulator used was a Mechtronix Fixed Base Boeing 737 NG Simulator, owned and operated by Boeing Flight Training Services Ltd.

Volunteers were recruited via email through each Australasian B737 NG operator's company email system. Although a larger sample size would have given a more powerful result, only 24 volunteers were sought due to constraints on simulator time available. While 25 pilots volunteered, only 18 could be accommodated due to geographical or availability limitations.

Each participant was paid $50 to contribute towards travel expenses.

6.1.1 Fixed Base versus Full Flight Simulator Fidelity

Early research into the effects of flight simulator motion cues (e.g., Briggs & Wiener, 1959; Flexman, 1966; Koonce, 1974; Roscoe, 1980) suggested that simulator motion was an important cue for pilot interpretation of spatial position and directional cues. Early airline flight simulators had very rudimentary visual displays, using either night-time only or dusk illuminations. Such simulators had very poor visual acuity in ground-based images and as such pilots were forced to rely on all cues, including simulator motion, to generate three-dimensional mental pictures of spatial position and motion.

Later research, however (e.g., Burki-Cohen, Go & Longridge, 2001; Burki-Cohenet al., 2003; Lee & Bussolari, 1986; Go, Burki-Cohen, & Soja, 2000; Hays, Jacobs, Prince, & Salas, 1992), indicates that the visual cues generated in a modern (post-2000) flight simulator are so realistic that the absence of motion cues is less critical. Indeed, the visual fidelity of a modern high quality fixed base flight simulator (FBS) approaches that of a full flight simulator (FFS) with very accurate computer-generated visual acuity.

While the sensation of movement is a pre-requisite for regulatory proficiency checking in Australia and most other countries, the FBS is used regularly in various airline training and recruitment applications. Burki-Cohen et al. (2003) showed that motion cues were useful for identification purposes during engine failure assymmetry type situations but were not a pre-requisite in other general manoeuvres. The go-around manoeuvre which was used in this study is largely conducted on instruments, without the need for sensory motion cues. The manoeuvre is discussed further below.

None of the pilots who participated in the experiment noticed any decrement in performance associated with a lack of simulator motion. The exercise was conducted predominantly in cloud with visual meteorological conditions only available on departure and below 100 feet AGL on each approach. The lack of visual cues in cloud and the total immersion in the task at hand appear to have contributed to the lack of sensitivity to motion in the FBS. Anecdotal evidence suggests that the participants quickly forgot that there was no motion.

6.1.2 The Simulator Exercise

The experimental task involved two instrument circuits, departing and arriving on runway 19 at Brisbane International Airport. The aircraft climbed to 3,000 feet, and then received radar vectors downwind (provided by the simulator instructor, a member of the research team). Once downwind the aircraft was vectored onto finals of the ILS approach for runway 19. This approach has a DA of 200 feet AGL (220 feet AMSL). For each exercise the cloud base was set at 100 feet AGL (100 feet below DA); this meant that the aircraft would not have the visual requirements to continue when it arrived at the DA, requiring a missed approach. Identical weights (60 Tonnes for take-off with six Tonnes of fuel) were used for each simulation. A diagram illustrating the exercise profile and the ILS approach plate for runway 19 at Brisbane are shown below in Figures 24 and 25.

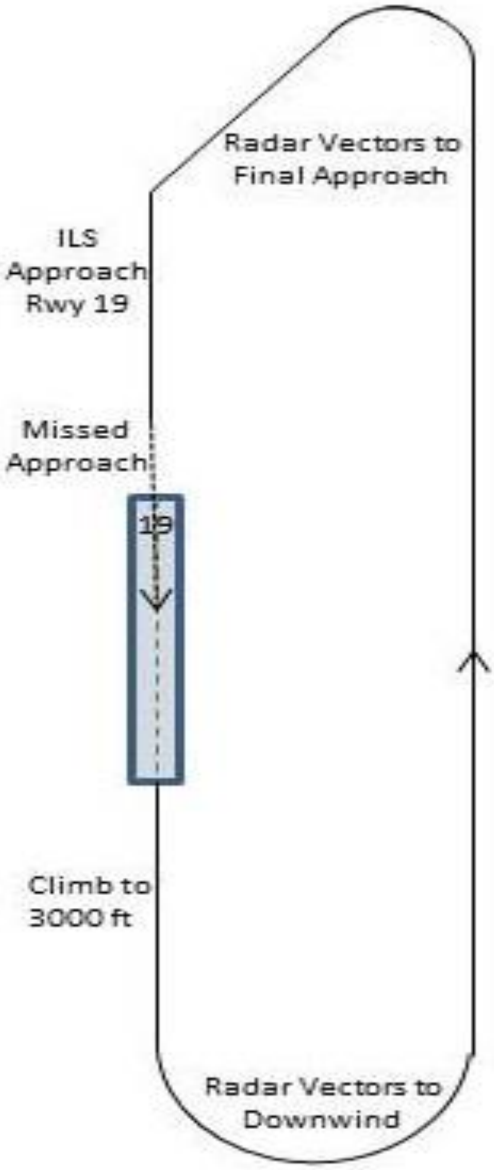

Figure 24 - Startle Simulator Exercise Profile

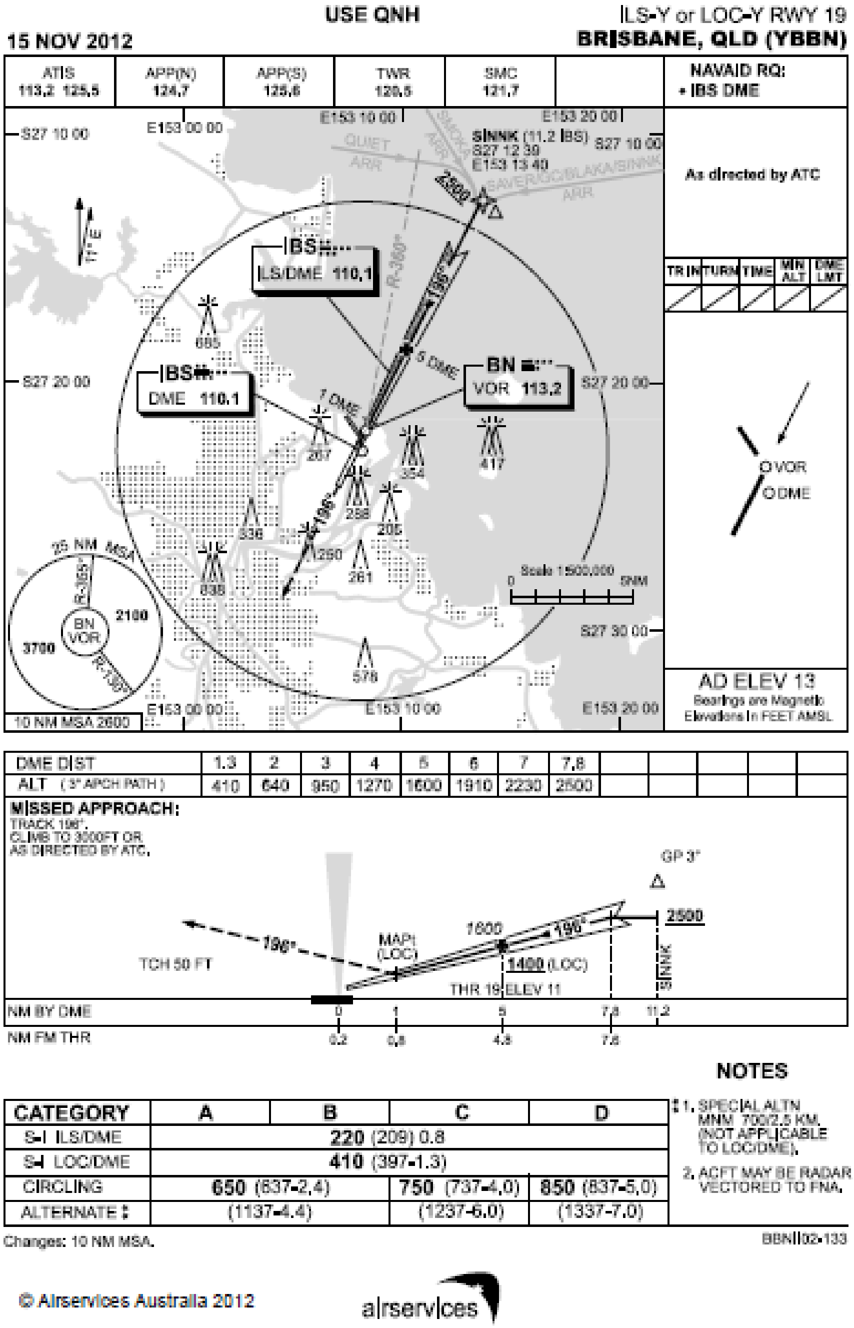

Figure 25 - ILS-Y Approach Plate Runway 19 Brisbane

From: http://www.airservicesaustralia.com/aip/pending/dap/BBNII02-133.pdf

6.1.3 The Go-Around Manoeuvre

The go-around manoeuvre used in this study does not involve any assymmetry and is largely a rotation around the pitch axis to a pitch angle. This manoeuvre is primarily done on instruments and doesn't rely on human sensory cues beyond visual ones. The manoeuvre involves pressing the TOGA button to initiate flight guidance and thrust changes which are programmed by various aircraft systems, coupled with pulling back on the control column until a go-around pitch angle is achieved. This angle is generally around 15 degrees nose-up but varies depending on aircraft weight, speed and ambient conditions. The manoeuvre also involves a call by the PF announcing the go-around to the PM, and a call for the flap to be retracted to the go-around flap setting.

Once a positive climb is established on the radar altimeter and instantaneous vertical speed indicator (IVSI), then the PM would call "positive rate" which the PF would use as a cue to call "gear up". This is a request by the PF for the PM to move the landing gear selector lever to the "up" position which initiates the retraction of the landing gear. The participants involved in the experiment all come from companies where SOPs are based on these manufacturer's guidelines (Boeing, 2012b).

During the go-around the PF would also be adjusting and stabilising the aircraft's pitch angle to follow the commanded pitch angle provided by the aircraft's flight director. The flight director consists of a crosshair-type display which commands both a pitch angle and tracking guidance to satisfy the climb and tracking requirements determined by the aircraft's flight control computer(s) for the configuration, weight, ambient conditions. A picture of the B737NG Primary Flight Display (PFD) with the flight director crosshairs is shown below in Figure 26.

Figure 26 - B737 PFD with flight director crosshairs shown.

Lateral and vertical tracking guidance during the approach is achieved using the ILS at the airport. The ILS transmits very accurate signals which the aircraft flight guidance computers interpret as both localiser (lateral) deviation, and glideslope (vertical profile) deviation. Where signals of off-localiser are received, these are indicated by the vertical flight director bar (localiser) moving to the left or right of centre, commensurate with the amount of deviation from centreline. Likewise, under or above desired vertical profile (normally 3°) are indicated by the horizontal flight director bar (glideslope) moving up or down commensurate with the amount of deviation from correct glideslope. This presentation provides visual guidance for pilots on where they are in relation to both localiser and glideslope and correctional inputs required to regain “on slope” and “on track”. For example, if the aircraft was low on glideslope and left of the localiser track, then the flight director would command a “fly up” and “fly right” command simultaneously to correct for these deviations. These indications are sufficiently accurate to allow hand-flown ILS approaches around the world down to a decision height of 200ft or less AGL. With autopilot(s) engaged, the system is sufficiently accurate to allow automatic landings and rollouts in heavy fog in some aircraft.

If insufficient visual cues for landing are available at the decision height (200ft AGL in the experiment), then a missed approach is to be commenced. This involves the go-around manoeuvre described above, in which localiser guidance automatically transitions to lateral navigation (LNAV) guidance 50 feet above the instrument approach minima and climb attitude guidance becomes generated by the flight control computers. The missed approach LNAV tracking is pre-programmed in the FMC for each approach and is a coarser tracking guidance than localiser indications during the approach itself.

Deflection of the flight director guidance varies with distance from the airport Localiser aerial whereas LNAV guidance is a linear scale, so there is a transition during the missed approach procedure from very accurate Localiser guidance to coarser LNAV guidance as a normal function of the autoflight system. LNAV tracking during the missed approach is sufficiently accurate to provide terrain clearance during the climb out, and is used ubiquitously in airline operations around the world for that reason, but is not as accurate as an ILS “back course”. For this reason it is easier to track when using LNAV for guidance.

Lateral tracking during the go-around manoeuvre was not found to be outside normal tolerances in the experiment.

6.1.4 The Independent Variable

Two of the three phenomena investigated in this research, denial and freezing, are generally induced as a result of severe and acute stress, and it was considered unacceptable and unethical to put research volunteers into a situation where they were acutely stressed. The deleterious effects of stress are considerable for some people and can persist for some time after a traumatic event.

For this reason the only phenomenon which was ethically able to be induced in the flight simulator was startle. Startle is an everyday reaction to which all humans are prone. It is a very short-lived phenomenon which generally has no ongoing physical effects beyond a few seconds. When a traumatic event is the startling stimulus, however, then it is conceivable that recurring bad memories of the event could occur. For this reason it was decided that the startling stimulus should be one to which airline pilots are regularly subjected and unlikely therefore, to have lingering concerns over.

6.1.5 The Startle Stimulus

The flight simulator has warning systems which produce loud auditory or tactile signals. Four of these were considered as the startling stimulus in the experiment trials to establish the most suitable one for the experiment proper. These were the fire warning bell, the EGPWS callouts, the TCAS resolution advisory callouts, and the stall warning stick-shaker.

The fire bell consists of a loud electronically-generated ringing noise. In an aircraft it is activated whenever there are indications of a fire in places such as the aircraft's engines, auxiliary power unit, cargo hold, or wheel well area. Pilots are routinely subjected to fire bells as part of their airline training and proficiency checking. Fires are one of the more common emergencies practised by pilots and for that reason the fire bell would be unlikely to have ongoing effects on the participants beyond the exercise.

The EGPWS has several auditory callouts, including both cautionary and warning messages (Honeywell, 2004). The most common ones experienced in the flight simulator during training and checking include terrain proximity warnings e.g., "terrain terrain" or "whoop whoop, pull up". Windshear warnings are another EGPWS facet and warnings such as "windshear, windshear, windshear" or "windshear ahead" are regularly encountered. False EGPWS warnings are also routinely generated by simulator instructors as a training or checking tool to develop or test pilots' ability to react correctly to a terrain or windshear warning. As EGPWS warnings are regularly experienced, pilots would be unlikely to have ongoing effects from warnings of this nature in the simulator experiment.

The TCAS is a system which is designed to provide both cautions and warnings to pilots when they are too close to another aircraft (Harman, 1989). Generally the first callout would be a cautionary one such as "traffic, traffic", which is generated with sufficient time for pilots to attempt a visual sighting and manoeuvring away from conflicting traffic. When aircraft are in very close proximity and in danger of collision, then the TCAS will generate a resolution advisory, which consists of an instruction on how to manage the aircraft's vertical flight path in order to avoid collision. An example would be "climb, climb" or "descend, descend". Like the fire bell and the EGPWS, pilots are routinely subjected to TCAS events in the simulator as both a training and proficiency checking tool.

The stick-shaker is a device which physically shakes the control column when speed reduces below a certain buffer above the aircraft stall speed for a given configuration and wing loading. It generally activates approximately 10 knots above the actual stall speed and continues until such time as speed is increased beyond this point or wing loading is reduced. As well as the physical shaking of the control column, the stick-shaker generates a loud clattering noise. Both the shaking and clattering are intended to alert the pilot to an impending stall so that recovery action can be initiated. Stall training with recovery at the stick-shaker activation are relatively common items in initial type training and recurrent training, so pilots are generally very familiar with the significance of the stick-shaker and would therefore be unlikely to suffer any prolonged effects caused by a stick-shaker occurrence.

6.1.6 Design of the Experiment

To determine the best startling stimulus, a trial was conducted in the Boeing 737NG Flight Simulator in May 2012 using members of the research team and a volunteer pilot who was current on the B737NG. Several iterations of the three audible warnings—engine fire bell, EGPWS terrain warning, and TCAS resolution advisory—plus the tactile stall warning stick-shaker, were generated to test the reaction on the volunteer pilot.
The stimulus was also generated at different phases of flight to establish the best time to administer the stimulus.

The following flight phases were trialled:

- during climb out after take-off;
- during straight and level flight;
- during a medium turn (approximately 25 degrees angle of bank); and
- immediately prior to the minimum altitude on an instrument approach where a go around was required.
-

The intent of the testing was to determine the effect of startle on a pilot's ability to fly the aircraft accurately and to measure any startle-induced delay in returning to the pre-determined flight path. The flight path deviation can be very accurately measured on the flight simulator instrumentation over a number of parameters, including altitude, heading and airspeed. The time to return to the pre-determined flight path was also discernible from the flight simulator telemetry, which can be printed out in hard copy, following each exercise.

At the end of the trial the data which proved most useful came from using the fire warning bell as the startling stimulus, especially when administered immediately prior to the minimum altitude on an instrument approach at which a go-around was required. Several stimulus activation altitudes were tested in the trial; however, the one that was chosen was 240 feet AGL or 40 feet above the DA. This proved to give a reasonable opportunity to perform nominally when unaffected but also showed the results of startle-induced delay where that proved to occur. The fire bell also proved most effective when a loud bang was coincidentally generated by one of the researchers at exactly the same time as the fire bell went off. The fire warning chosen was the cargo fire warning, which, when received at the same time as a loud bang, created a scenario of an explosion in the cargo hold. The loud bang was achieved by simply hitting a panel in the rear of the simulator just as the aircraft reached 240 feet radio altitude. This was quite easy to achieve with very good consistency.

The following data was gathered for the analysis:

1. minimum altitude achieved during the go around, and
2. any other iterations of non-standard behaviour such as: failing to retract the flap to go-around flap, failing to retract the landing gear, descending significantly below DA during the go-around, or using non-standard go-around procedures.

To allow for inherent individual variations in ability and reactionary times, a baseline performance was used as a comparison tool. This allowed data to be compared on an individual basis with and without startle. To achieve this, an exercise was designed which incorporated two instrument circuits, with two approaches and missed approaches. To avoid introducing additional variables caused by possible learning or expectation, each experiment involved the startling stimulus being introduced during the first approach. Participants were advised that the startle could occur at any time and all of the candidates experienced some level of startle ranging from mild to strong.

The simulator exercises were filmed using a video camera which was focused on the instrumentation. The videotapes were analysed post-exercise and used to confirm measurements of flight path and speed.

6.1.7 Analysis

Both quantitative and qualitative analyses were conducted following the simulator exercises. Quantitative analysis of several parameters was conducted. Data was analysed using an SPSS Analysis tool, including:

- Reaction delta

  This was the minimum altitude achieved on the first approach (following startle) compared to the actual and average minimum altitudes achieved on the second approach without startle. A one-sample *t*-test was conducted on the approach one reaction data to determine the statistical significance of any difference between the results and the comparison level of 166 feet.
- Age

  A Pearson *r* correlation test was conducted to determine whether there was a correlation between increasing age and reaction delta following startle. A one-sample *t*-test was also conducted on the age/performance data to determine the statistical significance of the results when compared to the comparison level of 166 feet.

- Rank

  A Pearson *r* correlation test was conducted to determine whether there was a correlation between rank (captain or first officer) and reaction delta following startle. A one-sample *t*-test was also conducted on the rank/performance data to determine the statistical significance of the results when compared to the comparison level of 166 feet.

- Experience

  A Pearson *r* correlation test was conducted to determine whether there was a correlation between experience (total flight hours) and reaction delta following startle. A one-sample *t*-test was also conducted on the experience/performance data to determine the statistical significance of the results when compared to the comparison level of 166 feet.

  .

Qualitative and quantitative data were obtained by demographic information prior to the exercise being flown and by survey questions on completion of the exercise. A copy of the demographic questions and survey questions are at Appendix A and B respectively. The following data were considered in the qualitative analysis:

- age,
- position (captain or first officer),
- total flying hours,
- total hours on B737,
- self-perceived level of startle,
- self-perceived physiological signs of startle,
- self-perception of indecision or confusion following the startle,
- the length of this confusion or indecision if applicable, and
- any other observation notes from the research team.

A Pearson r correlation test was conducted to determine whether there was a correlation between self-perceived startle and approach 1 delta.

6.2 Simulator Experiment Results

The aim of this experiment was to examine whether there was a difference between the pilots' performance at baseline and their performance once exposed to a startling stimulus. Both quantitative data and qualitative data were examined in the analysis.

The experiment involved two hand-flown instrument approaches where the weather was such that a missed approach would be required on reaching the DA. On the first approach a startling stimulus (cargo fire warning bell and coincident loud bang) were administered at 240 feet AGL (40 feet above the DA). There was no stimulus on the second approach.

The 18 participants were current Boeing 737 NG type rated pilots of varying experience levels from three Australasian airlines. Twenty-four volunteers were sought, however only 21 pilots volunteered to participate. Of these three were unable to attend due to rostering requirements and other clashes. Of the remaining 18 volunteers, all met the requirements (type rated, current B737 NG pilots) and participated in the experiment.

The hypothesis was that on an approach with no startle, a missed approach would be commenced at or close to the manufacturer's guidelines for altitude lost on a missed approach (200ft DA – 30ft altitude loss = 170ft minimum altitude on go-around), but on the approach with a startling stimulus there would be a delay in commencing missed approach due to some startle-induced information processing delay or other cognitive impairment manifestations such as in decision-making.

Consideration was given to randomising the order of the approaches with and without startle. Randomisation would have been useful in eliminating candidate pre-conceptions, but it could have introduced a strong confounding variable. Making approach one the startle approach eliminated any experimental bias caused by a change in expectations, or practice effects, which could have interfered with the quality of the data obtained. The order of approaches was therefore kept consistent to avoid introducing confounding variables into the data.

None of the pilots had any concrete expectation of when the startle would occur, although the structure of the exercise and the requirement to hand-fly below 1500 feet would have given them some level of expectation that the startle would occur during one of the approaches. Had some of the participants not received a startle on the first approach, then their expectation level for a startle occurring during the second approach would have been justifiably higher. The implications of this in terms of increased arousal and subsequent performance are undeterminable without further testing. The effects of practice on second approach performance would also have been a further confounding variable and this further added to the reason for standardising the order of the approaches.

Other metrics were considered for comparison. These included the time to press the TOGA button (to initiate the go-around), time to achieve a stable climb out flight path following go-around, and lateral tracking during the go-around. The TOGA button initiation was measurable, but created an additional variable. It is possible to commence a go-around by manually selecting full thrust and pulling up without ever touching the go-around button. This would generate accurate results in the minimum altitude achieved, but distort the results which measured time to press TOGA. It was also confounded by those approaches in which pilots didn't press TOGA at all. The time to achieve stable climb out flight path was also subject to too many variables and to discrepancies in determining at exactly what point the climb out was considered stable.

Finally, there was no discriminatory data shown in the lateral tracking metric. None of the missed approaches showed any determinable variation in lateral tracking that could be attributed definitively to startle. Tracking actually showed very good results and was therefore considered not worthy of inclusion.

6.2.1 Go-Around Results

Table 9 shows the results obtained in order of the minimum altitude lost on the startled approach (approach 1). Note that the initial approaches which resulted in minimum altitudes of 200 and 220 feet were considered pathological responses because the missed approaches were commenced before the aircraft reached the DA and therefore were an impulsive response that could have prevented the aircraft from landing with a potentially significant emergency. Similarly, the results which show zero feet for the minimum altitude are those two aircraft that landed without attempting to go around. The cloud base was set at 100 feet AGL (100 feet below DA) and in three cases, the approach was continued in IMC so far below DA that the pilots concerned became visual. In all three of these cases the approach was unstable, with two of the three being badly unstable. One of these badly unstable approaches eventually resulted in a very late go-around.

Candidate	Stimulus Alt Radio AGL	App 1 Minimum Alt on Go Around	App 2 Minimum Alt on Go Around	Reaction Delta App 1 from 166’
		(with stimulus)	(no stimulus)	
a	240 ft	170	170	4
b	240 ft	170	140	4
c	240 ft	170	190	4
d	240 ft	160	110*	-6
e	240 ft	160	170	-6
f	240 ft	150	180	-16
g	240 ft	150	160	-16
h	240 ft	150	170	-16
i	240 ft	150	170	-16
j	240 ft	140	170	-26
k	240 ft	140	160	-26
l	240 ft	200	170	-34**
m	240 ft	220	160	-54**
n	240 ft	86	140	-80
o	240 ft	66	150	-100
p	240 ft	56	180	-110
q	240 ft	0 (Landed)	150	-166
r	240 ft	0 (Landed)	190	-166
			Mean: 165.9*	

Table 9 - Quantitative Experiment Data

*In determining the average minimum altitude obtained on approach 2 (the baseline comparator approach), the 110 feet minimum altitude on go-around was considered an outlier. A normal missed approach which resulted in a height loss of 90 feet would generally be considered unacceptable were it flown on a recurrent proficiency check. Removing this outlier result gave a mean minimum altitude for go around of 166 feet (165.88) which is comparable to the manufacturer’s guideline of 30 feet height loss (i.e., 170 feet with a DA of 200 feet as used in this experiment) (Boeing, 2012).

** The approach 1 minimum altitudes of 200 and 220 have been included as negative deviations as they were regarded as pathological responses. In both cases the missed approach was initiated prior to the DA.

This allowed a comparison between the mean minimum altitude in the go-around (166 feet) and the actual minimum altitude achieved. A one-sample two-tailed *t* test showed that there was a significant difference (p= 0.026) between the mean minimum altitude in the go around (approach 2) and the actual minimum altitude achieved in approach 1. Alpha was set at 0.05, M= 129.9 feet, SD = 62.6 feet.

Several additional quantitative and qualitative variables were used to provide some descriptive data around the experimental results. These included:

- age,
- position (CAPT or FO),
- total flying hours,
- total hours on B737,
- self-perceived level of startle,
- self-perceived physiological signs of startle,
- self-perception of indecision or confusion following the startle,
- the length of this confusion or indecision if applicable, and
- any other observation notes from the research team.

To establish whether performance following startle was related to other factors, analyses were conducted for the following data:

- startle performance and age,
- startle performance and rank (captain vs. first officer), and
- startle performance and total flying experience.

These analyses are outlined below.

6.2.2 Age

Table 10 lists the relationships between reaction delta (approach 1) and participant age.

Reaction Delta (166' vs. App1)	Age
-4	35
-4	35
-4	40
6	33
6	30
16	37
16	28
16	33
16	50
26	57
26	35
34	41
54	51
80	46
100	49
110	29
166	46
166	52

Table 10 - Reaction Delta (App 1) vs. Age

The scatter plot in Figure 27 illustrates the correlation between age and the startle performance observed on approach 1 (r = 0.41). This correlation was not significantly different from zero (p=0.091).

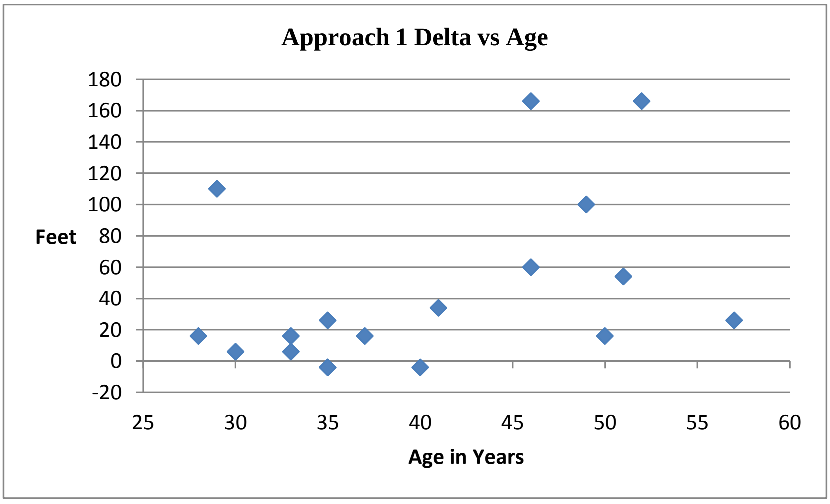

Figure 27 - Approach 1 Delta vs. Age

The scatter plot shows that, with one exception, the larger approach 1 deltas were from pilots in the 46-57 year age group.

6.2.3 Rank

Table 11 lists the relationships between rank and reaction delta (Approach 1)

Reaction Delta (166' vs. App1)	Rank C=CAPT F=FO
-4	C
-4	F
-4	C
6	C
6	F
16	F
16	C
16	C
16	F
26	C
26	C
34	F
54	C
80	F
100	C
110	F
166	C
166	C

Table 11 - Reaction Delta (App 1) vs. Rank

Figure 28 shows the relationship between rank and reaction delta (approach 1).

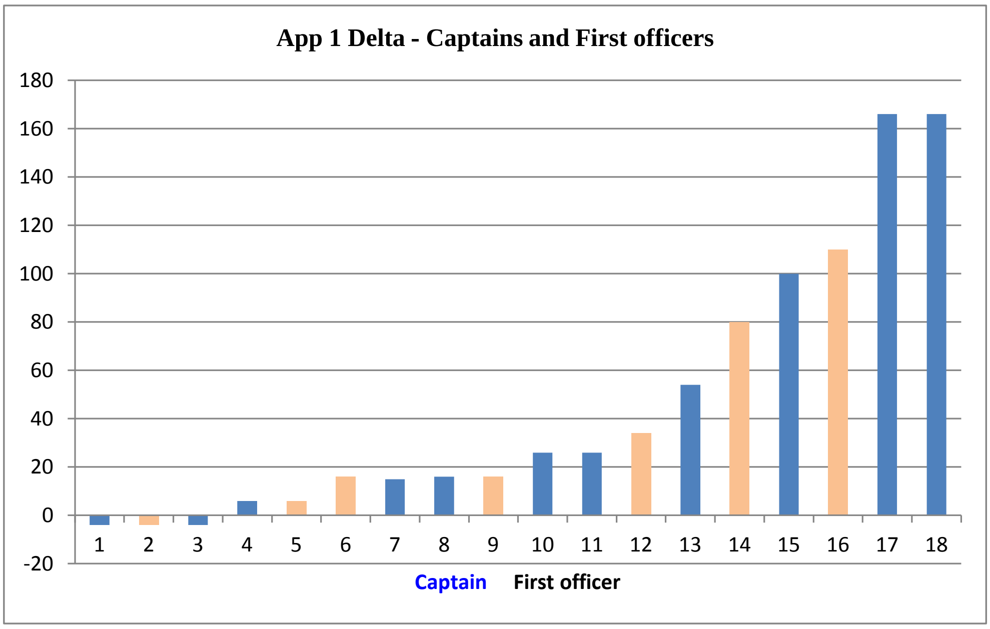

Figure 28 - Approach 1 Delta vs. Rank

An independent sample *t*-test was conducted and showed that rank was not a significant factor in the performance results (p=0.518).

6.2.4 Experience

Table 12 lists the relationships between hours flown (total experience) and reaction delta (approach 1):

Reaction Delta (166' vs. App1)	Experience (Total Hours)
-4	6400
-4	4600
-4	13600
6	5000
6	2600
16	9000
16	5300
16	8500
16	8000
26	19800
26	8500
34	6000
54	10200
80	15000
100	14000
110	3040
166	6000
166	11500

Table 12 - Approach 1 Delta vs. Experience

Figure 29 shows the relationship between total flying experience and reaction delta. It shows that there is a minimal correlation between experience and the startle performance observed on approach 1 (r = 0.116) which is not significantly different from zero (p=0.646) when compared via a single tail t-test.

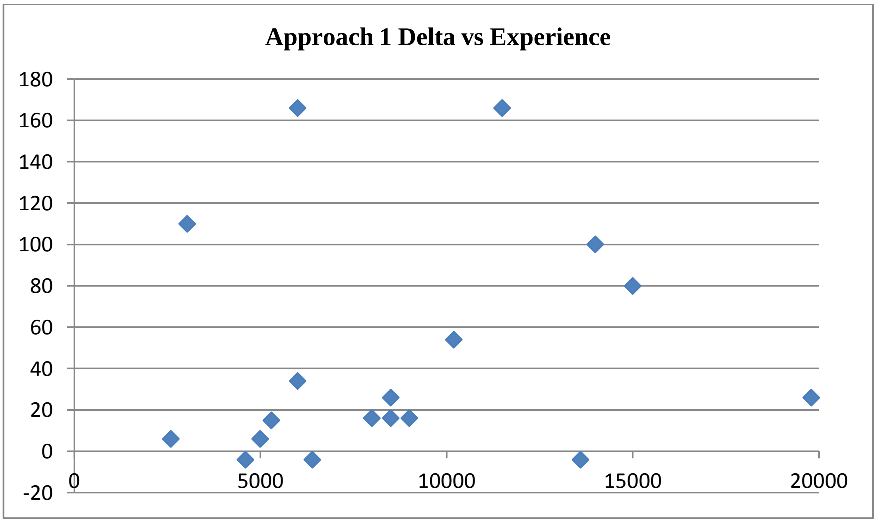

Figure 29 - Approach 1 Delta vs. Experience

In addition to these metrics a mix of quantitative and qualitative physiological data was collected. The results are shown at table 13:

Candidate	Reaction Delta (166' vs. Approach 1)	Physiological Signs Experienced	Confusion or Indecision?	Estimated Duration	Self-perceived Startle (1-10)
a	-4	HR[3], Adrenaline[4]	Yes	10-15 secs.	7.5
b	-4	HR,	Mild	Strategic	4
c	-4	Mild Adrenaline	NIL	NIL	2
d	6	HR, Adrenaline	NIL	NIL	6
e	6	HR, Respiration, Adrenaline	YES	4-5 secs.	7
f	16	HR, Respiration,	YES	2 secs.	3
g	16	HR, Adrenaline	YES	1 sec.	5.5
h	16	NIL	NIL	NIL	7
i	16	NIL	NIL	NIL	3
j	26	Mild HR, Adrenaline	YES	N/A	2
k	26	Adrenaline	YES	2 secs.	8
l	34	HR, Perspiration	YES	5 secs.	7
m	54	HR, Adrenaline	YES	0.5-1 sec.	7
n	80	NIL	NIL	NIL	3
o	100	HR	NIL	NIL	6
p	110	HR, Adrenaline	YES	2 secs.	7
q	166	HR, Respiration, Adrenaline	NIL	NIL	4
r	166'	Mouth Dry	Yes	3-5 secs.	8.5

Table 13 - Physiological Data from Simulator Research

[3] HR is heart rate increase
[4] Where adrenaline has been noted, this has been based upon the pilots' perception of physiological changes which are typified by adrenaline being released into the bloodstream.

Table 14 shows the relationship between the level of self-perceived startle and approach 1 delta. It should be noted that while the reaction delta from 166 feet (approach 1) is quantitative data, self-perceived startle level is an entirely subjective evaluation based on each individual's perception of their level of startle. This perception can be biased by several factors, including experience of previous startle, their interpretation of a slight startle and a strong startle, and recollection of the level of startle intensity some 20 minutes after the event.

Self-perceived startle level was used instead of a clinical measure of startle or acute stress, such as tongue swab, heart rate monitor or blood pressure monitor, in order to make performance as naturalistic as possible. The presence of clinical measuring equipment may have negatively impacted on pre-event stress levels, which could, conceivably, have distorted the natural startle performance which was observed. It was not intended that the qualitative measure of self-perceived startle be used categorically as a measure of startle intensity, but rather the intention was to use it as a qualitative contextualisation metric around the quantitative results. While correlations between self-perceived startle and post-startle performance are examined below, they provide little data which could be used for definitive conclusions.

Candidate	Reaction Delta App 1 from 166’	Self Perceived Startle (1-10)
a	4	7.5
b	4	4
c	4	2
d	-6	6
e	-6	7
f	-16	3
g	-16	5.5
h	-16	7
i	-16	3
j	-26	2
k	-26	8
l	-34[5]	7
m	-54[14]	7
n	-80	3
o	-100	6
p	-110	7
q	-166	4
r	-166	8.5

Table 14 – Reaction 1 Delta vs Self-perceived Startle Level

A Pearson *r* test showed a non-significant level of correlation between approach 1 delta and self-perceived startle (r = -0.21).

6.2.6 Limitations

Simulator time is very expensive, so obtaining sufficient pilots and simulator time to generate high-quality statistical data is difficult. The desire for statistical power had to be tempered by the amount of available simulator time and therefore a sample size of 24 (one per simulator hour) was settled on. However, while the desired sample size was 24 pilots, only 18 pilots could participate. This is a small sample size and therefore statistical power is lower than desired.

[5] While the actual delta values of these results was positive (i.e. greater altitude than 166 feet), the pathological nature of these performances justifies their inclusion as a “difference from 166 feet”. This has been represented as a negative value for convenience.

6.2.7 Discussion

The results obtained during the startle trials indicated that overall around one third of pilots performed nominally and seemed to be largely unaffected by the startle. Another third showed some slight delay in initiating the go around, but showed no significant impairment. The other third showed some interesting behaviours and performance levels where the effects of the startle were quite likely to have influenced their performance.

There was a reasonable range of ages and experience levels in this experiment, with no clear relationship between experience and performance. There was some correlation with increasing age and reduced performance which warrants further research. These correlations were not statistically significant when analysed via a single sample, two tailed *t*-test.

The correlation between self-reported perception of startle level and performance was low. It could be argued from these results alone that the level of startle was not correlated to post-startle performance, however it is more likely that the perception of what was a strong startle versus a weak startle, was at the heart of this disparity. Subjective perception of startle, which was not sampled until approximately 20 minutes after the stimulus, was perhaps somewhat flawed. It would be interesting to see whether this subjective perception would be different if next time it was done immediately after the startle event. Regardless, the results of this correlation add little weight to the startle related performance data, but are included for information.

Female pilots formed a small percentage of participants (n=1). The sample size makes it impossible to determine whether gender plays any part in post-startle performance, however no significant difference effects were noted in this experiment. Once again there is scope for further research in gender differentiality following startle, which appears to have been largely ignored in the research to date.

Chapter 7 DISCUSSION AND CONCLUSIONS

7.1 Overview

The research question in this study asked whether phenomena such as startle, freeze and denial were likely to create pathological behaviours in pilots which in turn could affect situation outcome during critical events in aviation. The data from accidents and incidents in recent history have shown that these phenomena may have contributed to negative outcomes. Similarly, personal accounts from pilots who have experienced critical events suggests that all these phenomena have occurred, although the fact that they recovered from them suggests that while they may have resulted in undesired aircraft states in some cases, the outcomes were generally positive for various reasons. Finally, simulator trials where pilots were subjected to a startling stimulus at a critical stage of flight have shown that around one third of pilots sampled exhibited behaviours which were considered worrisome in a flight safety context.

7.2 Discussion on Startle

The prevalence of startle in the historical and autobiographical case study analyses suggests some performance decrement is possible when people have been surprised by a startling stimulus, particularly in conditions where real danger to life exist or there is a perceived threat to safety. Additionally, there appeared to be a very temporary impairment following startle in the case studies gleaned from interviews with pilots. While some admitted to being startled for 3-5 seconds, the outcome from most of these critical events was largely one of successful recovery. In those few incidents where a negative outcome developed, it appears that the effect of startle on pilot performance was at least moderate, certainly enough to disrupt normal problem-solving, decision-making and situational awareness processes.

The analyses of accident case studies from the literature revealed clear examples of pilot performance which was below expectations. In some cases pilots made ineffective recovery responses, while in other cases the control response was totally inappropriate or even counterproductive, contributing to a deterioration in the aircraft state. Several of these inappropriate response incidents resulted in lengthy periods of incorrect response which ultimately contributed to a negative outcome. The Colgan Air accident, the Pinnacle Airlines accident, and the West Caribbean Airways accident were just three examples of flight control responses following startle which were the opposite of those required for a successful stall recovery. To pull the aircraft nose up to 52°, to repeatedly overcome a stick pusher, or to repeatedly pull back on the control column while in an obvious (to anyone else) state of aerodynamic stall suggests that those pilots' cognitive processes were at least disrupted to a point where they were unable to implement a standard stall recovery.

Similarly, in the Air France flight 447 accident, and the Turkish Airlines accident, the pilots in control took some action, but it was either inappropriate for the automation configuration they were in or was rapidly countermanded by aircraft systems which were acting in accordance with their programmed routines. The inability of the FP in AF447 to interpret the information from the aircraft displays and warning systems and from the other pilot, who told him that the aircraft was in an alternate law automation mode, and to then make a more appropriate recovery control response, suggests that pilot was unable to integrate this information and to implement an appropriate solution. In the Turkish Airlines accident, the nine-second delay in restoring a significant amount of thrust suggests a breakdown in very basic stall recovery techniques.

The simulator startle research demonstrated a breakdown in normal go-around procedures in some pilots. While the results must be tempered by the small sample size and consequent lack of statistical power, the behaviours exhibited by some of the participants were indicative of disruption in normal cognitive processes. A decision to go around from the DA should have been straightforward. It is a decision which each pilot would have made several times in their careers when lacking visual contact with the runway environment at the appropriate decision point. Their delay in acting would appear at face value to be attributable to some element of confusion following the startle, which is likely consistent with that experienced by pilots in the other case studies.

While the simulator startle research showed some delays in reacting amongst the majority of pilots, the pilots who continued descending below 100 feet showed some extended delay in effecting an appropriate response. The descent from 200 feet AGL (DA) down to 100 feet AGL (where they broke clear of cloud), took approximately 10 seconds, depending on the rate of descent at the time. Even this is a lengthy period of time to make what should be a recognition-primed decision to go around. Pilots practise this exact scenario in the simulator every few months, and experience it in real life occasionally. Their training involves multiple iterations of this decision-making and implementation of the go-around manoeuvre.

Three of the approaches which continued below 100 feet became very unstable. Two of them developed a high rate of descent, between 1,200 and 1,450 feet per minute, which resulted in multiple EGPWS warnings of "sink rate". Of these three unstable approaches, two continued to a landing, while one resulted in a very late go-around (minimum altitude 56 feet). Unstable approaches are sometimes precursors to runway overruns or excursions and as such the behaviours which allowed these situations to develop were likely pathological. Pilots are generally trained to ensure approaches remain within strict stable limits, which are normally rates of descent less than 1,000 feet per minute below 1,000 feet (Boeing, 2012). Most airlines require an immediate go-around if an approach has become unstable, however the late go-around, or failure to go around in these cases contravened these conventions.

Deviations significantly beyond normal operational expectations, as several of the simulator approaches were, suggest some form of cognitive disruption which would be in keeping with that reported by startle researchers such as Thackray and Touchstone (1970) Vlasek (1969) and Woodhead (1959, 1969). These disruptions caused breakdowns in normal procedures which had potentially negative situation outcomes.

Evidence from the case study analyses, the interview studies and the simulator experiments suggests breakdowns in normal processes following startle have real potential to contribute to accidents, incidents or undesired aircraft states. Further research on the effects of startle on pilot performance is warranted.

7.3 Discussion on Freezing

The phenomenon of pilots freezing during critical events has clearly negative implications, and while the data obtained through case study analyses and interviews appears to show a relatively low incidence of this phenomenon, several of the incidents examined had negative outcomes as a result of behavioural inaction or caused undesired aircraft states which were eventually recovered.

The events examined with negative outcomes (Air France Flight 5672, Tamworth training accident and Air France Flight 358) showed that behavioural inaction during acutely stressful critical events could degrade behaviour to a degree where the outcome was catastrophic. In each of these cases the FP appeared to have been overcome by a rapidly deteriorating situation which was likely perceived as acutely stressful, and their cognitive processing appears to have been severely impaired as a result. They took no action to recover their entirely recoverable situations.

Two other severe manifestations of behavioural inaction were only overcome through luck or severe physical intervention. In the case of the captain who froze during approach (event 5b), the first officer was unable to wrest control from the completely unresponsive pilot, and was about to revert to knocking the captain out with a large torch when the aircraft broke clear of cloud and the captain recovered enough to regain profile, albeit in a very coarse manner. This event nearly ended in a negative outcome, as the captain narrowly avoided an apartment building as he recovered the correct profile. It would appear as if good fortune played a large part in the successful outcome of this event, which could easily have ended in tragedy.

The event in which the pilot froze during spin recovery (event 33b) implied another cognitive disruption of high magnitude. As the spin developed the PF froze on the controls, and instructor had to resort to physically hitting the PF in order to regain control, albeit right on bailout altitude. In this case the PF displayed a severe case of behavioural inaction which could easily have had a negative outcome had the instructor not intervened. The ramifications for the instructor of continuing to fight for control below minimum bailout altitude, versus abandoning the aircraft and the student to save his own life, were particularly unsavoury. It was fortunate that he was able to overcome the PF when he did, or the situation would likely have deteriorated into a negative one.

Each of these incidents and accidents, and the other manifestations of behavioural inaction discussed in the case studies, suggests that the effects of acute stress during critical events are sufficiently overwhelming to interfere with cognitive processing. It appears that in severe cases pilots can become behaviourally inactive at a time when action is required to save themselves and their aircraft. The effects on situation outcome of a pilot freezing or experiencing behavioural inaction are potentially disastrous.

7.4 Discussion on Denial

The effects of denial are difficult to quantify. While it is likely that brief moments of disbelief are common during unexpected critical events, the manifestation of tactical denial, which appears to be an acute stress coping mechanism, are difficult to identify other than through self-report. More strategic denial of information which is potentially threatening is more common and easier to examine. Certainly denial is a common phenomenon in life, and has received moderate attention in the medical literature.

In the case study analyses, self-reports of momentary disbelief were attributed largely to the after-effects of startle. The cognitive disruption which appears to be common following a strong startle appears to engender a range of behaviours and thoughts which may be counterproductive or inactive. In analysing these behaviours, particularly when momentary disbelief was mentioned by pilots, some determination was required as to whether this was in fact denial or startle-induced disruption. This determination was that the disruption which occurred was better attributed to startle than to denial due to its transient nature. The momentary disbelief would appear to have had no impact on situation outcome in the cases where this was mentioned.

In terms of strategic denial, the Air Transat incident (event 9a), where the pilots ignored obvious indications of a rapidly deteriorating fuel state, was a case in which the crew chose to ignore potentially threatening information by positive interpretation. To avoid discussing the possibility of a fuel leak or even consider it suggested they were impaired by some factor which made the determination of a simple fuel imbalance more palatable than the implications of a fuel leak.

It is difficult to categorically state that denial occurred in the Saudi Airlines incident (event 15a), but circumstantial evidence would strongly suggest that the captain, while facing an immensely stressful emergency, failed to accept the seriousness of the situation. By continuing to taxi while a fire was raging in the cabin of his aircraft suggests some breakdown in normal cognitive processes. Whether it was a denial of urgency or denial of the threatening information which should have been obvious to him, he appears to have simply ignored it, which directly resulted in a negative outcome.

The Swissair accident (event 26a) also showed a disregard for the urgency and level of threat posed by a fire on the flight deck. It seems incomprehensible that a captain would ask for delaying manoeuvres while a fire was burning in his cockpit, but that is exactly what happened. The cognitive processes that led to the Swissair 111 captain's decision-making appear to have been deeply flawed and are likely to have been influenced by some denial of the urgency and level of threat posed by the fire. While it is unclear whether the aircraft could have landed safely if they had diverted directly to Halifax airport, the apparent denial of the threat may have been directly causal in the situation outcome.

The two incidents in which dynamic denial was described by self-report (events 11b and 28b) were included solely because the pilots involved described mental processes of denial. These were examples of tactical denial, but were relatively short-lived.

Evidence suggests that in some cases, denial of threatening information, or of the urgency of required action, have been directly causal in aviation accidents. Failure to take action when (to a retrospective observer) there was information available to suggest urgent action was required is indicative of some denial-like process. As an acute stress coping process, it is possible that denial could prevent effective action, so can lead to irrecoverable situations.

7.5 Conclusions

This study identified many instances in which pathological behaviours are likely to have contributed to or been directly causal in aircraft accidents, incidents or undesired aircraft states. The study showed that startle is likely when pilots are suddenly confronted with an unexpected threatening stimulus, and develops beyond a simple reflex into fear-potentiated startle, which generates physiological arousal and other effects. The effects of strong startle have been shown to cause significant disruption to cognition in some cases, resulting in impairment in situational awareness, decision-making, problem-solving and communication processes. Startle has also been shown to cause significant deterioration in psychomotor performance in some cases. This disruption to cognition and psychomotor performance has been shown in laboratory tests to last for up to 30 seconds, a considerable period in critical situations where rapid and effective corrective action may be necessary to avert disaster (Thackray, 1988).

Simulator tests showed around two thirds of pilots involved in startle research displayed some delays in acting, or impulsive actions. Approximately one third appeared to be badly affected, and displayed pathological behaviour for some time after the startling stimulus was administered. These behaviours led to unstable approaches, delays to the commencing of go-around, and generally to a significant degradation in normal levels of flight safety.

Several accidents and incidents studied also showed considerable disruption which was likely due to startle. Colgan Air Flight 3407 (event 1a) and Air France Flight 447 (event 2a) are just two recent accidents in which startle was considered by investigators as being directly causal in the accident. Pilots in these and other accidents displayed ineffective or inappropriate behaviour which contributed to or caused a negative outcome.

The modern airline aircraft is a very sophisticated, automated, and reliable machine and, where pilots some 30-40 years ago had a healthy expectation for failures because equipment regularly failed, the modern airline pilot rarely experiences real failures. This has the effect of developing a conditioned expectation for normality, an unconscious complacency, borne out of ubiquitous reliability. It appears therefore, that when today’s pilots are suddenly confronted with unexpected, critical events, their lower level of expectation for such an event, coupled with their reduced real-life exposure to handling such events, may create fear-potentiated startle in some cases. This can then induce pathological behaviours where ineffective or inappropriate actions, or indeed, complete inaction results.

Freezing and denial have been shown to be pathological behaviours associated with acute stress. Freezing, a term described in this context as behavioural inaction, has been shown to be caused largely by an overwhelming of the cognitive system. In this phenomenon the WM appears to be overcome with task-irrelevant, anxious thoughts, and any executive control over constructive thought processes is lost or at least temporarily suspended. When behavioural inaction has occurred at a critical stage of flight, such as is thought to be the case with Air France Flight 358 (event 22a), then the outcome has been catastrophic. Other serious cases of freezing have only narrowly avoided disaster, sometimes through the intervention of others, with several severe manifestations in this study (e.g., event 5b and event 33b) being cases in which physical violence was used to overcome the frozen state.

Likewise, in those cases where some level of denial has occurred as a stress coping mechanism, particularly at a critical time, the outcome has been negative. Coping has been shown to be a strategic process, and may in fact be a long-term, perseverant defensive trait in some people. By contrast, dynamic situations where a development is suddenly appraised as uncontrollable often result in emotion-focused coping mechanisms such as denial being employed. This tactical denial is a short-term stress relief mechanism which may have contributed to many aviation accidents and incidents.

It can only be surmised from the inactivity on CVRs recovered from some catastrophic accidents that complete tactical denial of all information was employed. The lack of recovery from a GPWS warning in the Independent Flight 1851 accident, for example, is a case where the presumed startle-induced inactivity, could instead have been caused by tactical denial. It is impossible to tell, given that no-one survived, but I chose to assess that particular accident as startle-related in the absence of the evidence of denial.

Some of the incidents and accidents studied here are likely to have involved some element of denial. Denial of urgency, followed by an even greater pathologically critical denial of threatening information, likely contributed to a catastrophic result in the Swissair Flight 111 accident (event 26a) for example and this would appear from the research to be typical. Additionally, self-reports from several pilots during interviews suggest that denial is common during stressful critical events.

7.6 Addressing the research question

The research question addressed in this study was:
Can pathological behaviours such as startle, freezing and denial during aircraft emergencies or unexpected events, significant enough to impact on flight safety?

In answering this question, evidence has been presented to suggest that all three of these pathological behaviours are capable, in critical situations, of negatively affecting situation outcome. There also appears to be considerable variation between people in their responses to crises, which may be partly trait-based, but may also be significantly affected by situational factors including the levels of stress and fatigue existing at the time. While some people may be more dispositionally inclined to react badly when suddenly challenged by a threatening situation or stimulus, no conclusive predictors other than stress and fatigue show consistent correlations. Further research with larger sample sizes may yield more conclusive data.

The results of the analysis presented herein implies that the three constructs of startle, freeze and denial have created pathological responses in some pilots at critical times and must be considered a continuing danger to flight safety.

7.7 Further research required

The pathological pilot behaviours explored in this study have received little previous attention in the aviation literature. A spate of recent high-profile aircraft accidents in which startle was identified as a contributory factor raised the profile of this phenomenon, and while considerable laboratory research has been done into both the startle reflex and fear-potentiated startle, there is a need for further research into the effects of startle on pilots and into interventions for better managing sudden, unexpected critical events. Of particular use would be more operationally-focused research that extends beyond the small sample experiments conducted in this study.

A systematic review of accident report data may be one means of further quantifying the prevalence of the pathological behaviours studied in this thesis. Such a review would provide useful data for further analysis of circumstances where these behaviours were most common, and possibly lead therefore to the development of mitigation strategies.

Research which examined variables such as stress level, fatigue, age and gender on startle effects would be worthwhile. The simulator experiments in this thesis showed some correlation between increasing age and the effects of startle, and it would be useful to obtain further information on this relationship. While the correlation with flying experience wasn't as clear, it would also be useful when considering interventions to explore whether different training methods are more effective with different groups based on age or level of experience.

Stress research in the aviation industry lacks attention to phenomena such as behavioural inaction and denial. There has been considerable work in the stress field, but the effects of acute stress in the aviation industry deserve more attention. It is possible that the same types of interventions which could one day result in improved startle performance following unexpected critical events could also improve self-efficacy in pilots enough to reduce the need for emotion-focused coping measures. The research on stress inoculation, while mostly conducted outside aviation, has suggested that greater exposure to stressful events builds a sense of self-efficacy and greater tolerance as a result.

Stress research is, by its nature, difficult to conduct in an operational setting, particularly in high-risk, high-consequence environments such as the aviation industry. Some research on passenger evacuations has yielded useful data, but there is considerable scope for further work in this area. In particular, the effects of low arousal in the incredibly sophisticated, automated and reliable aircraft (which are now common), and the results of a sudden increase in arousal from this subdued state, would be a useful study.

The effects of denial will always be difficult to quantify, but further qualitative analysis, particularly with people who have survived critical events, may yield useful data. Interventions based on greater awareness of the phenomenon may be one avenue worth exploring, but the limited amount of literature on tactical and strategic denial processes in the aviation warrants considerably more attention.

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APPENDICES

Appendix A Synopses of Incidents and Accidents in the Chapter 4 Systematic Review

The following synopses have been included to illustrate the pathological behaviours which may have contributed to the incident and accident in question. Each synopsis is followed by an analysis and an attribution of likely pathological behaviour.

Event 1a: Colgan Air Q400 accident Buffalo-Niagara Airport, January 2009

Synopsis

On 12 February 2009, a Colgan Air Bombardier DHC-8-400, N200WQ, operating as Continental Connection flight 3407, was on an instrument approach to Buffalo-Niagara International Airport, Buffalo, New York, when it crashed into a residence in Clarence Center, New York, about five nautical miles northeast of the airport.

As the aircraft commenced its approach to Buffalo-Niagara on autopilot it levelled out at 2300 feet and Flap 5 was selected. At that time the airspeed was 180 knots. From there the captain commenced slowing the aircraft with the power levers reduced to near flight idle. Shortly after this the landing gear was lowered and the condition levers were moved to maximum rpm. At around this time airspeed was 145 knots and was followed shortly after by the captain asking for flaps 15[6]. The Flight Data Recorder (FDR) showed the flaps only being selected to 10°, however, as the airspeed reduced to about 135 knots. About six seconds later the stick-shaker (impending stall warning device) activated and the autopilot was disconnected. At this stage the speed was 131 knots.

Following the stick-shaker activation, the FDR showed that the control column was moved aft and that engine power increased to about 75% torque (significantly below maximum torque). While the torque was still increasing to this point the aircraft pitched up, rolled left 45° and then rolled right. The aircraft's stick-pusher system (which acts to automatically lower the nose during a stall) then activated. The first officer then announced that she had raised the flaps,

[6] Flaps are lift augmentation devices which are lowered incrementally during approach to increase lift, allowing the aircraft to fly slower for landing.

which was confirmed by the flaps retracting. This would have had the effect of increasing the aircraft's stall speed, exacerbating the stall condition. At this stage the airspeed was about 100 knots. The aircraft continued to roll right to about 105° right wing down before the airplane began to roll back to the left and the stick-pusher activated a second time. The aircraft then reached 35° left wing down before rolling back to the right. The first officer then raised the landing gear as the aircraft pitched to 25° nose down and rolled to 100° right wing down. The aircraft impacted the ground a short time later, with the flaps fully retracted.

The following three findings were extracted from the 46 in the NTSB report (NTSB, 2010):

> Finding 11: The captain's response to stick-shaker activation should have been automatic, but his improper flight control inputs were inconsistent with his training and were instead consistent with startle and confusion. (p. 152)
>
> Finding 12: The captain did not recognize the stick pusher's action to decrease angle-of-attack as a proper step in a stall recovery, and his improper flight control inputs to override the stick pusher exacerbated the situation. (p. 152)
>
> Finding 15: Although the reasons the first officer retracted the flaps and suggested raising the gear could not be determined from the available information, these actions were inconsistent with company stall recovery procedures and training. (p. 152)

The NTSB also determined that the probable primary cause of the accident was "the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover…." (NTSB, 2010, p. 155).

Analysis

While the presence of aircraft icing may have contributed to the early onset of the aircraft stick-shaker and subsequent stall, sufficient cues were available to the crew to recognise the approaching stall conditions. The accident report also suggests that the commuting of the two pilots to their operating base may have contributed to their being slightly fatigued. Notwithstanding these issues, the Cockpit Voice Recorder (CVR), which was subsequently read by the NTSB, showed signs of surprise or startle, which the NTSB noted may have contributed to the inappropriate recovery responses by both the captain and first officer.

When confronted with an unexpected stimulus (stick-shaker) and potentially threatening situation (impending stall), the pilot showed signs of becoming startled and pulled back on the control column. This had the effect of raising the nose and causing the airspeed to decrease below the stall speed for the aircraft weight and configuration. Once the aircraft had stalled the pilot flying was incapable of executing a standard stall recovery and displayed behaviours consistent with fear-potentiated startle. The breakdown in information processing caused by the strong and enduring startle reaction seems to have prohibited the pilot flying from recalling the correct stall recovery procedure, or at least from implementing it.

The first officer, in retracting the flaps to zero, without direction, exacerbated the stall condition and made recovery more difficult. Her decision to raise the flaps is also consistent with confusion following an unexpected critical event, which may have been induced by a strong startle, in the same manner as the captain.

Determination of Pathological Behaviour

The behaviours exhibited by both the captain and first officer are typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus was experienced in the aural, visual or somatic modalities, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

Event 2a: Air France Flight 447 Loss of Control Inflight, Atlantic Ocean, 1 June, 2009

Synopsis

While in the cruise from Rio de Janeiro to Paris at FL350, the Airbus A330 encountered icing conditions associated with extensive thunderstorm activity approximately four hours after departure. Shortly afterwards the captain departed the flight deck to begin a period of rest, leaving two first officers on the flight deck as operating crew. Around eight minutes after the captain left the flight deck, an obstruction in the pitot tubes caused by a build-up of ice crystals created anomalies in the speed indications on the flight deck.

The following extract from the BEA report describes the ensuing events:

> At 2 h 10 min 05, the autopilot then the auto-thrust disconnected and the PF said "I have the controls". The aeroplane began to roll to the right and the PF made a nose-up and left input. The stall warning triggered briefly twice in a row. The recorded parameters showed a sharp fall from about 275 kt to 60 kt in the speed displayed on the left primary flight display (PFD), then a few moments later in the speed displayed on the integrated standby instrument system (ISIS). The flight control law reconfigured from normal to alternate. The Flight Directors (FD) were not disconnected by the crew, but the crossbars disappeared.
> At 2 h 10 min 16, the PNF said "we've lost the speeds" then "alternate law protections"[7]. The PF made rapid and high amplitude roll control inputs, more or less from stop to stop. He also made a nose-up input that increased the aeroplane's pitch attitude up to 11° in ten seconds.
> Between 2 h 10 min 18 and 2 h 10 min 25, the PNF read out the ECAM messages in a disorganized manner. He mentioned the loss of autothrust and the reconfiguration to alternate law. The thrust lock function was de-activated. The PNF called out and turned on the wing anti-icing.
> The PNF said that the aeroplane was climbing and asked the PF several times to descend. The latter then made several nose-down inputs that resulted in a reduction in the pitch attitude and the vertical speed. The aeroplane was then at about 37,000 ft and continued to climb.
> At about 2 h 10 min 36, the speed displayed on the left side became valid again and was then 223 kt; the ISIS speed was still erroneous. The aeroplane had lost about 50 kt since the autopilot disconnection and the beginning of the climb. The speed displayed on the left side was incorrect for 29 seconds.
> At 2 h 10 min 47, the thrust controls were pulled back slightly to 2/3 of the IDLE/CLB notch (85% of N1). Two seconds later, the pitch attitude came back to a little above 6°, the roll was controlled and the angle of attack was slightly less than 5°.
> From 2 h 10 min 50, the PNF called the captain several times.

[7] Alternate law is a degraded flight control mode which offers fewer flight envelope protections than normal modes

At 2 h 10 min 51, the stall warning triggered again, in a continuous manner. The thrust levers were positioned in the TO/GA detent and the PF made nose-up inputs. The recorded angle of attack, of around 6 degrees at the triggering of the stall warning, continued to increase. The trimmable horizontal stabilizer (THS) began a nose-up movement and moved from 3 to 13 degrees pitch-up in about 1 minute and remained in the latter position until the end of the flight. Around fifteen seconds later, the ADR3 being selected on the right side PFD, the speed on the PF side became valid again at the same time as that displayed on the ISIS. It was then at 185kt and the three displayed airspeeds were consistent. The PF continued to make nose-up inputs. The aeroplane's altitude reached its maximum of about 38,000 ft; its pitch attitude and angle of attack were 16 degrees.

At 2 h 11 min 37, the PNF said "controls to the left", took over priority without any callout and continued to handle the aeroplane. The PF almost immediately took back priority without any callout and continued piloting.

At around 2 h 11 min 42, the captain re-entered the cockpit. During the following seconds, all of the recorded speeds became invalid and the stall warning stopped, after having sounded continuously for 54 seconds. The altitude was then about 35,000 ft, the angle of attack exceeded 40 degrees and the vertical speed was about -10,000 ft/min. The aeroplane's pitch attitude did not exceed 15 degrees and the engines' N1's were close to 100%. The aeroplane was subject to roll oscillations to the right that sometimes reached 40 degrees. The PF made an input on the side-stick to the left stop and nose-up, which lasted about 30 seconds.

At 2 h 12 min 02, the PF said, "I have no more displays", and the PNF "we have no valid indications". At that moment, the thrust levers were in the IDLE detent and the engines" N1's were at 55%. Around fifteen seconds later, the PF made pitch-down inputs. In the following moments, the angle of attack decreased, the speeds became valid again and the stall warning triggered again.

At 2 h 13 min 32, the PF said, "[were going to arrive] at level one hundred". About fifteen seconds later, simultaneous inputs by both pilots on the side-sticks were recorded and the PF said, "go ahead you have the controls".

The angle of attack, when it was valid, always remained above 35 degrees.

From 2 h 14 min 17, the Ground Proximity Warning System (GPWS) "sink rate" and then "pull up" warnings sounded.

The recordings stopped at 2 h 14 min 28. The last recorded values were a vertical speed of -10,912 ft/min, a ground speed of 107 kt; pitch attitude of 16.2 degrees nose-up, roll angle of 5.3 degrees left and a magnetic heading of 270 degrees. (BEA, 2012).

Analysis

The accident investigation specifically identified startle as a possible contributory factor and both Air France and Airbus examined this phenomenon and the management of its effects in various forums after the event. The report contains the following reference to startle:

> The excessive nature of the PF's inputs can be explained by the startle effect and the emotional shock at the autopilot disconnection, amplified by the lack of practical training for crews in flight at high altitude, together with unusual flight control laws. (BEA, 2012, p. 175).

The chaotic management of the flight path following the icing encounter, accompanied by inappropriate and counterintuitive control inputs for an obvious stall situation, were in keeping with the information processing failures common following startle which ensued throughout the final minutes of the flight. It appears that the PF was unable to integrate the information presented to him, including clear indications of a stall, and continued to apply control inputs on the sidestick controller which were counterproductive to regaining control. The nature of the control devices fitted to the Airbus meant that the PNF was unable to recognise the fact that the PF was applying aft control pressure and was therefore seemingly unaware that the problem was being exacerbated by the PF. The contribution of startle to this event has been widely researched and has been implicated by investigators in the situation outcome (BEA, 2012).

Determination of Pathological Behaviour

The behaviours exhibited by the junior first officer (PF) are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules or training expectations.

- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 3a: Turkish Airlines Flight 1951, Loss of Control Inflight, Schiphol Airport, 25 February, 2009

Synopsis

The B737-800 aircraft was making an approach to Schiphol Airport in Amsterdam with a training captain, trainee first officer, and a qualified “safety” first officer on the flight deck. Air traffic control (ATC) had kept the aircraft slightly high on profile, requiring the crew to capture the ILS Glideslope from above, a situation which required minimal thrust and a higher than normal rate of descent to achieve the capture. The late turn onto the ILS Localiser by ATC, which prevented the crew in descending on the normal glidepath, created additional workload for the crew, which ultimately resulted in them being preoccupied with configuring the aircraft and completing the landing checklist at a time when normal monitoring procedures may have picked up the non-normal situation which was developing.

An undetected fault in the captain’s radio altimeter which had developed during the descent caused it to erroneously read -8 feet, while the first officer’s radio altimeter continued to read correctly. The first officer, who was PF, was unaware of the captain’s radio altimeter problem and continued to fly the autopilot-coupled approach. As the aircraft finally captured the ILS glideslope, the aircraft commenced a descent in accordance with the ILS Glideslope, but the aircraft’s autothrottle system, which was cued from the captain’s radio altimeter reading of -8 feet, reduced the thrust below a normal flight idle setting to a “retard flare” mode, which provides a lower level of thrust which would not normally be used until below 27 feet when the aircraft commenced its flare for landing. As a result of this reduced thrust setting, the aircraft was unable to maintain the speed selected on the mode control panel and it continued to decrease until the aircraft stick-shaker (stall warning) operated at an altitude of 460 feet.

The following extract from the accident report describes the ensuing crew actions:

> The first officer responded immediately to the stick shaker by pushing the control column forward and also pushing the throttle levers forward. The captain however, also responded to the stick shaker commencing by taking over control. It is likely that this caused an interruption to the first officer’s selection of thrust. The result of this was that

> the autothrottle, which was not yet switched off, immediately pulled the throttle levers back again to the position where the engines were not providing any significant thrust. Once the captain had taken over control, the autothrottle was disconnected, but no thrust was selected at that point. Nine seconds after the commencement of the first approach to stall warning, the throttle levers were pushed fully forward, but at that point the aircraft had already stalled and the height remaining, of about 350 feet, was insufficient for a recovery." (Dutch Safety Board, 2010, p. 6).

Analysis

The activation of the stick-shaker stall warning was likely an unexpected stimulus for both the captain and first officer. Despite speed indications showing deteriorating airspeed, an increasingly high nose-up attitude, and flashing visual indications on the aircraft speed tape, the crew seemed totally unaware of the developing critical situation. The initial response of the first officer to the stall warning was largely correct, with an application of substantial thrust which may have alleviated the situation had the autothrottles not retarded the thrust (as they were designed to do). This situation was complicated by the captain assuming control, but not restoring full thrust. He disconnected the autothrottle, but made no effort to apply full thrust for some nine seconds, during which time the speed continued to decrease until a full aerodynamic stall was entered. The remaining height was then insufficient to recover from a full stall.

The nine-second delay from the captain in applying full thrust was contrary to normal stall management techniques. The B737-800 stall recovery technique involves immediately applying full thrust while lowering the nose slightly, a technique common in virtually all aircraft. This commonly results in very little height loss and would probably have been successful had the captain done this when the stall warning activated at 460 feet. His failure to apply thrust for nine seconds was typical of a pilot who was somewhat confused by the unfolding events while in a state of high arousal. It is very likely that he was startled by the unexpected stick-shaker and suffered degradation in information processing as a result. The critical nature of the event in close proximity to the ground would in all likelihood have exacerbated his arousal level, amplifying the startle-induced impairment.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

Event 4a: Pinnacle Airlines Flight 3701, Loss of Control Inflight, Jefferson City, Missouri, 2004

Synopsis

On 14 October, 2004 two pilots were re-positioning a Pinnacle Airlines Bombardier CL-600 aircraft from Little Rock to Minneapolis-St Paul airport in Minnesota, with no passengers or other crew on board. The crew demonstrated some non-standard and somewhat unprofessional procedures during the flight, including an unexplained series of rapid “pull-ups” after departure which resulted in a vertical load of up to +2.3g, followed by a push-over resulting, in one instance, in a stick-shaker stall warning followed by a 0.6g push-over. This was followed by a seat switch at approximately 14,000 feet during which time it is presumed that both flight crew seats were temporarily unoccupied.

Some time later the captain requested a climb to the maximum certified altitude (FL 410) and subsequently received a clearance to do so. The following extract from the accident report describes the remaining events:

> About 2151:51, the first officer stated, “there’s four one oh my man.” About 2152:04, the CVR recorded the first officer laughing as he stated, “this is … great.” FDR data showed that, about 2152:08; the airplane was in level flight at 41,000 feet. FDR data also showed that the airplane climbed from 37,000 to 41,000 feet at an airspeed that decreased from 203 knots/0.63 Mach at the start of the climb to 163 knots/0.57 Mach as the airplane levelled off. The FDR data further showed that the autopilot vertical speed

> mode was engaged during the climb with a commanded vertical speed of 500 fpm and that the airplane's angle of attack (AOA) at 41,000 feet was initially 5.7º ….
>
> About 2154:07, the captain told the first officer, "were losing here. We're gonna be … coming down in a second here." About 3 seconds later, the captain stated, "this thing ain't gonna … hold altitude. Is it?" The first officer responded, "it can't man. We … (cruised/greased) up here but it won't stay." About 2154:19, the captain stated, "yeah that's funny we got up here it won't stay up here."
>
> About 2154:32, the captain contacted the controller and stated, "it looks like we're not even going to be able to stay up here … look for maybe … three nine oh or three seven." About 2154:36, the FDR recorded the activation of the stickshaker. FDR data showed that, at that point, the airplane's airspeed had decreased to 150 knots, and its AOA was about 7.5º.
>
> The FDR recorded activations of the stickshaker and the stickpusher three times between 2154:45 and 2154:54. FDR data showed that, after the second activation of the stickshaker and stickpusher, the No. 1 (left) and No. 2 (right) engines N1 (fan speed) and fuel flow indications began decreasing. FDR data also showed that, at the time of the second stickpusher activation, the airplane's AOA had increased to 12º and that, after the stickpusher activated for the third time, the pitch angle decreased from 7º to -20º.
>
> About 2154:57, the FDR recorded the fifth activation of the stickshaker and the fourth activation of the stickpusher. Even with the stickpusher's activation, the motion of the airplane continued to increase its AOA to the maximum measurable value of 27º. The pitch angle increased to 29º, and the airplane entered an aerodynamic stall. Afterward, a left rolling motion began, which eventually reached 82º left wing down, the airplane's pitch angle decreased to -32º, and both engines flamed out. About 2155:06, the captain stated to the controller, "declaring emergency. Stand by." FDR data showed that, during the next 14 seconds, the flight crew made several control column, control wheel, and rudder inputs and recovered the airplane from the upset at an altitude of 34,000 feet. During the recovery, the CVR recorded a sound similar to decreasing engine rpm, and FDR data showed that the No. 1 and No. 2 engines'N1 indications continued to decrease and that the engines" fuel flow indications were at zero. (NTSB, 2007, p. 22).

Following this the crew tried unsuccessfully to restart the engines but eventually crashed 2.5 miles south of Jefferson airport (NTSB, 2007).

Analysis

Despite the apparently unusual handling and seat change events during the climb, the crew eventually climbed successfully to the maximum certified ceiling for the aircraft type. It would appear however, that on this particular day, the aircraft had insufficient thrust available to maintain airspeed and the aircraft eventually stalled. At the time of the first stall warning indicated speed was just 150 knots and the aircraft was in a nose-up attitude of +7.5°. The captain appeared to have recognised the deteriorating airspeed situation some 30 seconds prior, but had not taken any steps to manage the flight path other than discussing a lower altitude with ATC.

Around three seconds after this discussion with ATC the first of five stick-shaker and stick-pusher events occurred, followed by deterioration in engine speed as both engines started to suffer flameouts. Over the next twenty seven seconds the flight crew made a series of coarse flight control inputs which resulted in pitch variations between -19.5º and +11º, eventually resulting in a full aerodynamic stall. As both engines continued to fail and the crew fought to recover from the stall, the aircraft continued descent, eventually crashing with both engines still failed.

Notwithstanding the apparently questionable airmanship practices preceding the loss of control event, the flight crew responded to the initial and subsequent stall warning iterations in a very uncontrolled manner which was consistent with impaired information processing and decreased psychomotor performance noted by researchers during startle and other acutely stressful events.

It is highly likely that the flight crew in this accident went very quickly from a light-hearted state to very rapidly being presented with a critical, life-threatening event, and that their arousal levels—either through fear-potentiated startle or the rapid onset of acute stress effects—impaired their ability to recover from this manageable event.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 5a: Air Canada Flight 189 DC-9 Overrun at Toronto-Pearson Airport, 26 June 1978

Synopsis

During takeoff at close to maximum weight, damage from a tyre failure caused a “gear unsafe” light to illuminate near the end of the take-off roll. The captain correctly decided to reject the take-off, but failed to execute the rejected take-off drill correctly, resulting in a runway overrun, killing two passengers.

During the take-off at approximately five knots below V1 (decision speed), at a speed of 145 knots, one of the DC9’s tyres burst and partially disintegrated. Fragments of the tyre were ejected into the landing gear assembly, damaging components of the landing gear sensor structure, which in turn generated a gear unsafe warning on the flight deck. Tyre debris also entered the number two engine, resulting in compressor stalling and a subsequent loss of thrust. The crew felt vibrations and heard a thumping sound. As the aircraft was below the go/no-go decision speed when the warning occurred, the captain correctly made the decision at a speed of 149 knots to abort the take-off with some 4000 feet of runway remaining.

Following the decision to abort the take-off the captain correctly closed the thrust levers, deployed the spoilers and selected reverse thrust, however the spoilers started to retract some 2.5 seconds later. The captain reselected the spoilers, however they once again auto-retracted some 4.5 seconds later. During this time the captain never applied any effective braking and the aircraft left the end of the runway at 70 knots, travelling some 457 feet before running over a precipice and into a ravine (Aviation Safety Net, nd; Stokes & Kite, 1994; Heaslip et al., 1991).

Analysis

Data from several sources described a situation in which a heavily laden jet suffered a tyre failure accompanied by engine and landing gear abnormalities very close to the take-off decision speed. The subsequent decision by the captain to reject the take-off 1 knot below V1 was a sound one, but the lack of braking by the captain during the subsequent deceleration, coupled with an anomaly in the spoilers which caused them to retract, meant that insufficient retardation was available from the remaining good engine to stop the aircraft before the end of the runway.

The response of the captain was initially correct; however, the failure of the captain to adequately apply effective braking was a direct contributing cause to this accident. Without direct evidence it is difficult to say conclusively why his performance was impaired, however, given the sudden and unexpected nature of the event at a critical stage of flight, it is highly likely that the captain would have been startled by the noise, the warning, and the tactile indications of the various failures. Despite rejected take-offs being routinely practised during simulator training and check flights, the possible unexpectedness of a failure so close to decision speed and the highly threatening nature of the ensuing rejected takeoff was likely to have created a very high level of arousal in the crew.

The captain’s failure to act in accordance with SOPs by immediately applying maximum manual braking was typical of other events in which people have suffered impaired information processing as the result of a startle.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.

- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules or training expectations.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 6a: West Caribbean Airlines Flight 708, Loss of Control Inflight, Venezuela, 2005

Synopsis

On 16 August 2005, flight WCW 708 was en route from Tocumen to Martinique when the crew decided to climb from FL310[8] to FL330 then accelerated to Mach 0.76. About 90 seconds later, following the application of anti-icing which adversely impacted on performance, the airspeed began to steadily decrease, with the horizontal stabiliser moving from about two degrees nose up to about four degrees nose up. About eight minutes later airspeed reduced to about M0.6, followed by a stall warning (which continued to operate for the remainder of the flight), the autopilot disconnecting, and a descent commencing. As the aircraft descended through FL315 the airspeed decreased further and the engine thrust decreased to about flight idle. The stabiliser also continued to increase in nose-up application until it finally reached maximum nose up (about twelve units NU) passing about FL200. The descent rate continued to increase with decreasing airspeed, reaching a minimum of 150 knots at about FL250. The crew advised ATC that they had suffered dual engine failure and variously requested lower descent altitudes, although at no stage did they declare an emergency. The aircraft impacted terrain 2 minutes and 46 seconds after the first onset of the stick-shaker (BEA, 2006; IASA, 2006; NTSB, 2005).

Analysis

The crew had failed to appreciate the effects of anti-ice on performance, having climbed to an altitude which was close to their service ceiling. As a result the airspeed started to reduce and the pitch angle started to increase, without either pilot noticing. Eventually the speed deteriorated and the stall warning stick-shaker activated, at which point the autopilot disconnected and a descent was commenced, albeit without any recovery in airspeed. Exacerbating the problem was a flameout in both engines which was never properly communicated to ATC as an emergency situation. The accident report suggests that crew situational awareness was poor prior to the stall and that communication and coordination

[8] Flight Level equates approximately to thousands of feet eg. FL 310 approximates 31,000 feet in altitude

during the emergency was inadequate. They failed to take appropriate action to recover the situation, despite ample opportunity to do so.

The flight crew, while clearly unaware of the developing deterioration in their situation, seemed somewhat overwhelmed and dealt with the stall situation inadequately. Their actions showed that rather than commence an emergency descent to recover airspeed, while lowering the nose-up attitude and restoring sufficient thrust, the crew continued to act in an inappropriate and ineffective manner. These reactions are typical of people who have been startled and/or in a high state of arousal induced by acute stress. Certainly the sudden and unexpected stimulus generated by the stall warning stick-shaker, which provides a tactile and auditory warning, would have likely induced some fear-potentiated startle. The lack of recovery may also have been exacerbated by the fact that the warnings continued throughout the descent, continually reinforcing the critical nature of the situation and maintaining a high level of arousal.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 7a: China Airlines Flight 006, Inflight Loss of Control, Pacific Ocean, 19 February, 1985

Synopsis

In 1985, a China Airlines flight from Taipei to Los Angeles was in the cruise at FL410, approximately 250nm west of San Francisco, when the number four engine flamed out. Contrary to recommended procedures, the captain elected to remain at FL410 on autopilot while an inflight restart attempt was made. The captain, who may have been suffering the effects of fatigue after being awake for some 24 hours, instructed the Flight Engineer to restart the engine while he monitored the process. During this time the captain failed to apply any rudder trim or rudder input, despite there being significant yaw from the asymmetric thrust. The B747 does not have automatic thrust asymmetry assistance and therefore the flight crew was required to manually compensate for the yaw induced by the engine asymmetry. Unfortunately, while the engine relight procedure was being followed, the crew failed to notice that the reduced thrust had led to deterioration in the aircraft's speed. To compensate for the adverse yaw which increased as the speed decayed, the autopilot attempted to maintain the aircraft in a wings level situation by continually increasing roll input, to the point where the control column deflection was approximately 23°. Shortly after this, as the autopilot reached its maximum limit of controllability, it automatically disengaged, with considerable roll inputs still in place. This resulted in the aircraft rapidly rolling into an almost upside-down state, followed by a rapid loss of altitude.

The captain, who had been monitoring the restart attempt, was surprised by the sudden loss of control and, in cloud, was unable to regain control for some time, confused by the unusual attitudes and suspecting an artificial horizon failure. The aircraft lost approximately 30,000 feet in two and a half minutes and control was only regained when the aircraft broke out of cloud, at which point the captain was able to visually level the aircraft out. During the descent control forces wreaked considerable damage on the aircraft with the wings being permanently bent upwards 2.5° and half the elevator torn off. The gear was also forced down through gravity and was then unable to be raised due to a loss of hydraulic pressure associated with the elevator damage (AviationSafety.net, 1985; NTSB, 1986).

Analysis

Research has shown that the effects of startle can be exacerbated both when people are tired or fatigued and when attending to or concentrating on something (Simons, 1996). Given the captain's extended period of wakefulness prior to the incident, coupled with the fact that he would likely have been attending to the relight sequence, the chances are that the sudden autopilot disconnect (with associated auditory warning) coupled with a rapid roll inverted would very likely have created a significant level of startle.

The captain's inability to integrate the information on his artificial horizon with other information, which persisted for some time, was then typical of impaired information processing following a strong startle, accompanied by very high levels of acute stress and arousal.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific Criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.

Event 8a: Air France Flight 5672, Controlled Flight Into Terrain, Guipavas, France, 22 June, 2003

Synopsis

During an approach to Guipavas Brest Airport in France, a Canadair CL600 deviated substantially from both Glideslope and Localiser until crashing well short and to the left of the runway. The following extract from the accident report (BEA, 2003), depicts the events of the approach:

> At 21 h 44 min 21 s, the controller cleared descent to three thousand feet and added "and perform a holding pattern". The aeroplane was approximately 20 NM DME from BG.
>
> At 21 h 47 min 40 s, that is, approximately one-and-a-half-minutes before the start of the hold, the controller cleared descent to two thousand feet QNH[9].
>
> At 21 h 48 min 01 s, the controller announced "Echo Charlie, preceding aeroplane has landed, continue the approach, report at Outer Marker". Four seconds later, at 9.4 NM DME, the autopilot "Heading" and "Vertical Speed" modes became active and the aeroplane adopted a heading of 257°. The Brest ILS frequency was displayed on the VOR 1 and the VOR navigation source was selected.
>
> At 21 h 48 min 21 s, the controller called back "Are you ready for the approach?". The crew confirmed and the controller asked "Report at Outer Marker". The Copilot read this back.
>
> At the captain’s request, the Co-pilot extended the flaps to 20° then the landing gear. The aeroplane stabilized at two thousand feet QNH on autopilot, still in Heading mode, at about 7 NM DME. Simultaneously, the wind, which had started to veer northwest during the descent, caused the aeroplane to drift towards the left. The flight crew did not notice this drift.
>
> At 21 h 49 min, the co-pilot extended the flaps to 30° then to 45° and the crew performed the pre-landing checklist.
>
> At 21 h 49 min 35 s, the controller cleared the landing for runway 26 Left and indicated a cloud base of less than one hundred feet.
>
> At 21 h 49 min 40 s, the aeroplane, in level flight, passed under then above the glide slope.
>
> At 21 h 50 min, the aeroplane passed the GU beacon, slightly to the left, with a track deviating to the left in relation to the localizer centreline. At that moment, the wind calculated by the Flight Management System (FMS) was 300° / 20 kt. A short time later, the aeroplane began its descent. The aeroplane continued to drift to the left of the localizer centreline.
>
> At 21 h 50 min 45 s the aeroplane again passed through the glide slope, and the captain said "Approach selected, LOC and Glide"; the Co-pilot confirmed. The autopilot

[9] QNH is the local air pressure in hectopascals or inches of mercury which is used for altimeter setting at lower altitudes. Using a locally promulgated QNH ensures that all aircraft in the area are using the same reference for altitude determination.

"heading" and "vertical speed" modes remained active. The aeroplane thereafter remained below the glide slope for the remainder of the flight.
Between 21 h 50 min 58 s and 21 h 51 min 02 s, the GPWS announced, successively, "Five hundred", "Glide slope" then "Sink rate".
At 21 h 51 min 01 s, the aeroplane began a turn to the right. By this time, the aeroplane was 4.68 points to the left of the localizer centreline.
At 21 h 51 min 04 s, the captain disengaged the autopilot.
At 21 h 51 min 05 s, the GPWS announced "Three hundred".
Between 21 h 51 min 07 s and 21 h 51 min 14 s, seven "Glide slope" alarms sounded. During this time, the co-pilot said "come right" on two occasions and the aeroplane attitude changed from - 5° to 0°.
At 21 h 51 min 15 s, the GPWS announced "One hundred".
At 21 h 51 min 16 s, with the aeroplane at 529 feet QNH and 93 feet on the radio altimeter, the Co-pilot said "Ive got nothing in front", then the captain said "Go around". Simultaneously, the engine thrust increased significantly. The aeroplane attitude returned to - 5 in four seconds, descending until it touched the ground 2,150 meters from the runway threshold, 450 meters from the extended runway centreline. The aeroplane struck several obstacles and caught fire (BEA, 2003, p. 12).

Analysis

This accident came about because of some automation mismanagement. The captain who was attempting to fly an autopilot-coupled ILS approach, left the autopilot in Heading (HDG) and Vertical Speed (VS) modes. These modes simply direct the aircraft to fly a selected heading and a selected vertical speed and are independent of ground-based guidance such as ILS. In this case the captain had apparently selected a heading of approximately the inbound course, but this did not provide any correction for wind, resulting in the aircraft continuing to drift left of track throughout the approach. Similarly, instead of capturing and flying a ground based precision glideslope of 3° the VS mode simply flies a vertical speed which is selected on a thumbwheel on the flight control panel (see Figure 30 below). In this case the aircraft was level at 2000 feet prior to commencing the approach and would have intercepted the ILS Glideslope from below had it been armed. Instead it maintained 2000 feet through the Glideslope until such time as the Captain made a manual selection of vertical speed on the VS thumbwheel. This had the effect of descending the aircraft back towards the required Glideslope, however, without the Glideslope mode being armed the aircraft simply continued through the slope and remained low on slope for the remainder of the flight. The following picture shows the flight control panel with the HDG and VS mode selectors highlighted as well as the VS thumbwheel.

Image removed

Figure 30 – Bombardier CL-600 Flight Control Panel

(BEA, 2003)

It appears that the captain initially recognised that the aircraft had not captured the approach mode (LOC and VS capture). This was evident from the fact that he manually selected a vertical speed when the aircraft failed to capture the ILS Glideslope, however, having done so he still failed to arm the Approach mode until the aircraft had gone through the Glideslope once again. This mode was therefore not armed until the aircraft was below glideslope and deviating further below, and was left of track and deviating further left, so the autopilot was never going to capture either the ILS Glideslope or Localiser without further intervention. At one stage the captain called *"Approach selected, LOC and Glide"*, which the first officer confirmed, however this would only appear to be in reference to the armed modes and never reflected any mode capture.That intervention never eventuated and the aircraft continued deviating left and below glideslope until it impacted the ground.

A plot of the actual track and glideslope against the published track and glideslope is shown below in Figure 31.

Image removed

From the time the aircraft descended through the glideslope until the go-around was initiated at 93 feet, there appeared to be little intervention from the PF other than a slight turn to the right following numerous Glideslope and Sink Rate warnings shortly after passing 500 feet, and the disconnecting of the autopilot and slight pitch up at 330 feet (probably as a reaction to the GPWS alerts). Regardless of these minor corrections, they were insufficient to return the aircraft to a safe profile and the DA (100 feet) was reached well left of the centreline and over 2km short of the runway. The first officer had uttered a couple of "turn right" calls during the latter part of the approach, and the captain had seemingly responded, however no effective action was taken until the slight turn at 500 feet.

It is certainly puzzling as to what mental processes were going on in the captain's mind; he seemed to be overwhelmed and not cognisant of the deviations in either glideslope or localiser. Medical examination post-mortem indicated no underlying condition which would have influenced his performance, therefore his performance must be considered as a deficit in the cognitive field.

It is highly likely that the captain would have been in an elevated state of arousal, as the very marginal weather conditions at the airport required a possible go-around and diversion, which, coupled with a late cancellation of the requirement for a holding pattern, combined to create high mental workload. Consequently the captain made several errors over the next few minutes, none of which were adequately managed. From the time the aircraft passed below the glideslope until the numerous warnings which commenced at around 500 feet (and were even then poorly managed), the captain took no action to effectively manage the flight path of the aircraft.

The possibility of behavioural inaction is suggested as a contributory factor, at least for some period of the flight between passing the glideslope and 500 feet. The captain's inaction could possibly be explained by an acute stress reaction where he was completely overwhelmed, creating a mental impasse in his working memory and preventing him from correctly interpreting the situation and then doing something to manage it.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, and in poor decision-making.
- While under conditions which were likely to be conducive of acute stress, there was no action taken when warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, and another pilot was forced to take control.

Event 9a: Air Transat Flight 236, All Engines-Out Landing Due to Fuel Exhaustion, Atlantic Ocean, 24 August, 2001

Synopsis

On the 24th of August, 2001, an Air Transat A330 was enroute from Toronto to Lisbon when the aircraft suffered a fuel leak. The crew first noted an imbalance at 0533Z at approximately 23°W and then commenced a diversion some 12 minutes later towards Lajes Airport in the Azores Islands. Approximately 30 minutes later one engine flamed out, followed by the other one approximately 12 minutes later. The aircraft made a successful glide approach and landing at Lajes Airport shortly after.

The fuel leak was shown by the Digital Flight Data Recorder (DFDR) to have commenced at about 0438 and worsened for some time. About 20 minutes later, while doing a routine instrument scan, the crew noticed an anomaly between the left and right oil pressures and temperatures, which they continued to monitor. They sent a message through to the company operations centre at 0521 advising them of the significant difference in oil pressures and temps. The company advised that they would review the data but that the readings were within allowable tolerances.

At 0533 the crew was presented with an advisory message telling them that there was a fuel imbalance of 3000kg between main tanks. The crew viewed the fuel synoptic page and at 0536 opened the fuel crossfeed valve and turned off the right pumps, establishing a crossfeed from the left wing tank to the right engine. Shortly afterward the crew also noted that the total fuel quantity remaining was significantly less than expected.

At 0554 the crew then reversed the direction of the crossfeed, routing fuel from the right tank to the left engine. At 0558 the “FUEL R WING TK LO LVL” message appeared, indicating that there had been less than 1640kg of fuel remaining in the right tank for 60 seconds, followed closely by the “FUEL L+R WING TK LO LVL” message around ten minutes later. The number two engine failed some fifteen minutes later, with the other engine failing around thirteen minutes after that (AAPID, 2004).

Analysis

The crew stated afterwards that although there were indications of a lower-than-expected fuel quantity which were recognised shortly after the fuel imbalance advisory message, they did not consider the fuel leak procedure until later in the flight (AAPID, 2004). Instead they described the fuel quantity and fuel predictions for destination as “unbelievable” and while they had discussed the term “fuel leak” several times during the occurrence, the real possibility of a fuel leak and therefore the fuel leak checklist option did not occur to them until only seven tonnes of fuel remained (AAPID, 2004). Indeed, the crew continued under the belief that the low quantity indications were caused by some type of computer error up to and beyond the flameout of the right engine (AAPID, 2004).

The Air Transat accident report goes on to discuss the concept and ramifications of "confirmation bias". This mental bias occurs when people form a mental model about the nature of their environmental cues and then lend more weight to subsequent cues which confirm this mental model, while ignoring or downplaying those cues which disconfirm their model. It is a bias towards relevant-appearing information and to overcome this process takes some cognitive effort, even in the light of contradictory information. This is described in the accident report as "psychological cost" or "dissonance involved in changing one's beliefs" (AAPID, 2004, p. 60).

This confirmatory bias can be viewed as a level of denial. Even when substantial evidence of a critical event was available, the crew of this flight chose to believe that it was a computer error, in the process exacerbating the problem to the extent that they ran out of fuel. Breznitz' (1983) hierarchy describes several stages of denial, with lower levels depicting denial of personal relevance and higher levels depicting the refusal to believe that information cues are not real. When considering the confirmation bias discussed here, it is appropriate to make the link between this bias and the denial stage which Breznitz calls "the denial of threatening information" (p. 260). In this stage of denial, Breznitz suggests that "by using a filtering device, sifting information in a biased fashion, those aspects of the stimulus situation which are particularly threatening can be minimised, reduced, or even avoided altogether" (Breznitz, 1983, p. 262).

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of denial. This determination is based on the following:

Underlying theme:
The pilots appeared to be tactically ignoring information which could be deemed as being of significant threat to their safety.

Specific criteria:

- An acutely stressful situation developed, or was perceived as developing, but without the presence of a surprising stimulus.

- A threatening stimulus was ignored, or the ramifications of it were ignored, in association with a period of acute stress.
- A serious or critical, and possibly deteriorating situation was unfolding, but inappropriate or no action was taken to address the problem.
- The perceived relevance of a stressor was ignored when it was actually relevant.

Event 10a: American Airlines Flight 965, Controlled Flight Into Terrain, Cali, 1995

Synopsis

While on descent into Cali, Colombia, the crew of an American Airlines B757 were cleared for an arrival onto runway 01 which was then changed to an arrival for runway 19. As the crew reprogrammed their flight management computer (FMC) for the new arrival, procedural and execution errors were made which initially led to the aircraft turning left approximately 120° towards Bogota, before the deviation was recognised by the crew. The crew, having lost situational awareness to some extent, appeared confused by their position and tried to confirm the correct arrival procedure with Cali ATC. They had been cleared via Tulua VOR (designator ULQ) and Rozo for the Rozo One arrival to runway 19, but by mismanaging the FMC had deleted ULQ from their flight plan and then deviated significantly away from their cleared route. The captain then decided to track direct to Rozo, in contravention of his original clearance, all the time continuing descent. Unfortunately, when the aircraft veered away from its assigned route, it crossed into an area of mountainous terrain, resulting in the aircraft descending towards some rising terrain. Approximately 13 seconds prior to impacting the terrain, the aircraft's GPWS sounded with "terrain, terrain, whoop, whoop". The captain uttered an expletive then disconnected the autopilot, applied full thrust and pulled up. During the terrain escape manoeuvre however, the captain failed to stow the speedbrake which had previously been extended to lose altitude, and the additional drag resulted in a reduced rate of climb. The aircraft just failed to clear the mountain and impacted about 250 feet from the peak, killing all but four on board (Wentworth, 1996).

Analysis

Research shows that the effects of startle are enhanced when people are already in an elevated state of arousal due to other stressors (Simons, 1996). In this case the captain, who was very confused about where the aircraft was and how to rectify the problem, was quite possibly in a moderately agitated condition as the aircraft continued descent towards the airport. The omission of the critical act of stowing the speedbrake was indicative of a breakdown in a well-rehearsed mental routine, quite probably induced by disruption to information processing systems as a result of startle. The sudden, unexpected GPWS warning, while in a slightly elevated state of arousal, in all likelihood resulted in a strong startle, with a subsequent critical breakdown in information processing. This had a direct effect on situation outcome as subsequent tests indicated that the aircraft may have cleared the terrain had the speedbrake been stowed.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 11a: Airbus A320, D-AXLA, 27 Nov 2008, Loss of Control near Perpignan, France

Synopsis

On the 27th of November 2008 an end of lease test flight was being conducted by Pilots from XL Airways under the supervision of the lessor, an Air New Zealand pilot representative. The flight was conducted in the vicinity of Perpignan, France and involved a series of both low- and high-altitude manoeuvres and checks. Following some high-altitude checks the crew failed to notice that both angle of attack vanes had failed, which would later have an effect on low-speed protection recovery.

As the aircraft returned towards Perpignan for an instrument approach it was decided to conduct a low-speed handling check which would test, amongst other things, the low-speed alpha floor protection, which is designed to prevent the aircraft from stalling. As the aircraft commenced speed reduction however, the combination of the AOA vane failures and a transition into direct law meant that the full up elevator trim which had developed automatically as the aircraft slowed to near stall speed, had suddenly transitioned into a manual trim mode. When the go-around thrust was then applied at the onset of the stall warning, the aircraft pitched up violently, without the automatic trim to counteract it. The aircraft continued to pitch up while rolling amidst a series of ineffective control inputs from the PF. The aircraft eventually entered a fully developed stall which could not be recovered from. During the pitch up manoeuvre following the go-around, pitch and roll became very unstable, reaching 57 degrees nose up and with roll varying from 50° right to 59° left (BEA, 2010).

Analysis

The CVR shows that following the violent pitch up which followed the application of go-around thrust, the captain appeared surprised and perturbed. His initial comments were *"oh, oh, oh…"* (BEA, 2010) and these were followed by a series of exclamatory remarks from the Pilot Monitoring (PM), the Air New Zealand pilot in the jump seat, and further comments from the captain.

The nature of the violent pitch up, coupled with the commentary from the CVR, suggests the crew were startled by the rapid turn of events and probably entered a very high state of arousal as the aircraft pitched and rolled violently in a manner which was particularly life-threatening. While the Air New Zealand captain in the jump seat had the wherewithal to recognise that the aircraft had passed into direct law[10], there was no indication from the captain that he had either recognised this, or if he had, that he had been able to understand its ramifications. At no stage did he attempt to apply nose-down trim which would have alleviated the critical pitch-up inputs created by the previously automatic trim system.

[10] Direct Law is a degraded flight control mode where significant reductions in flight envelope protection are available

It is highly likely that the impairment in information processing which resulted from a strong startle, followed by a period of very high arousal due to acute stress, prevented the captain (in particular) from recognising the underlying problem with the full-up trim and lack of automatic trim compensation, which inevitably led to the loss of control and subsequent accident.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 12a: Fairchild-Swearingen SA227-AC Metro III Loss of Control Inflight, New Plymouth, New Zealand, 2005

Synopsis

On the night of Tuesday 3 May 2005, Fairchild-Swearingen SA227-AC Metro III aircraft ZK-POA, operated by Airwork (NZ) Limited, was on a night air transport freight flight with two crew and 1790kg of cargo when it suffered an in-flight upset which developed into a spiral dive. The crew did not recover control and the aircraft became overstressed and broke up. Both crew members were killed and the aircraft and cargo destroyed.

The crew was balancing fuel between tanks, flying the aircraft at an excessive sideslip angle with the rudder input trimmed, while on autopilot. The autopilot capability was exceeded and it disengaged, precipitating the upset. The following extract from the accident report describes the events.

> At about 2212:28, after power was reduced to a cruise setting and the cruise checks had been completed, the captain said, "Well just open the crossflow again … sit on left ball and trim it accordingly". The only aircraft component referred to as "crossflow", and operable by a flight deck switch or control, was the fuel crossflow valve between the left and right wing tanks.
>
> The captain repeated the instruction 5 times in a period of 19 seconds, by telling the FO to, "step on the left pedal, and just trim it to take the pressure off" and "get the ball out to the right as far as you can … and just trim it". The FO sought confirmation of the procedure and said, "I was being a bit cautious" to which the captain replied, "don't be cautious mate, it'll do it good".
>
> Nine seconds later the FO asked, "How's that? The captain replied, "That's good – should come right – hopefully it's coming right." There was no other comment at any time from either pilot about the success or otherwise of the fuel transfer.
>
> During this time, the repeated aural alert of automatic horizontal stabiliser movement sounded for a period of 27 seconds, as the stabiliser re-trimmed the aircraft as it slowed from the higher speed reached during cruise at climb power.
>
> Forty-seven seconds after opening the crossflow, the captain said, "Doesn't like that one mate … you'd better grab it." Within one second there was the aural alert "Bank angle", followed by a chime tone, probably the selected altitude deviation warning. Both pilots exclaimed surprise.
>
> After a further 23 seconds the captain asked the FO to confirm that the autopilot was off, but it was unclear from the CVR whether the captain had taken control of the aircraft at that point. The FO confirmed that the autopilot was off just before the recording ended at 2213:41. The bank angle alert was heard a total of 7 times on the CVR before the end of the recording.
>
> During the last 25 seconds of radar data recorded by ATC, Post 23 lost 2000 ft altitude and the track turned left through more than 180º. Radar data from Post 23 ceased at 2213:45 when the aircraft was descending through FL199 about 1700 metres (m) southeast of the accident area. (TAIC, 2005, p. 2).

Analysis

The cause of this accident was an inflight break-up which resulted from a loss of control. The event occurred because the crew, who were attempting to balance the fuel between wings, had artificially induced a right wing down situation using rudder and rudder trim, in order to generate the flow of fuel from one wing to the other. This manoeuvre had been conducted on autopilot (which was being used in contravention of the Aircraft Flight Manual AFM above FL200), and it appears that as the autopilot attempted to maintain altitude and heading, it had gradually applied more and more aileron servo until it reached its servo limit. At that point the autopilot disconnected and the aircraft, with a substantial amount of aileron and rudder trim set, rolled very quickly to the left and commenced a rapid descent.

The accident report describes the recovery procedure for a spiral dive as:

- reduce power to minimise airspeed increase
- roll the aircraft to wings-level, then
- pitch the aircraft up to the horizon. (TAIC, 2006, p. 25).

There is some evidence that the crew had made roll inputs to try and counteract the rolling moment, however these had been accompanied by a strong upward input on the elevators. This was probably done to try and arrest the descent, but had the effect of exacerbating the spiral dive. Additionally the power levers do not appear to have been closed until some 18 seconds after the loss of control, which contributed to the runaway airspeed as the spiral dive unfolded. Once the aircraft exceeded 300 kts (75 kts above maximum operating speed (Vmo)) it rapidly experienced excessive vertical acceleration and broke up shortly after. The report suggests that recovery was a possibility up until this point. There is also some evidence that the first officer was still flying the aircraft, with the captain providing some instructions on the recovery. Normal procedure in this type of event would be for the more experienced captain to immediately assume control; however, the evidence in this case suggests this did not happen. There is no doubt that this event would have created a strong startle as the aircraft went from controlled to uncontrolled flight very rapidly. Additionally, the first officer at least, who was relatively new to this type of aircraft, had showed signs of anxiety and heightened arousal immediately prior to the event in being cautious with the rudder deflection and trim, probably due to concerns about directional control. This was overridden by the captain who pushed him to input extreme rudder and rudder trim inputs.

The actions of the first officer in neglecting to close the power levers and in pulling heavily on the elevator controls is consistent with a breakdown in normal unusual attitude recovery procedures, and is likely to have been hindered by cognitive impairment following a strong startle. Similarly, the inaction of the captain in not taking control suggests he was impaired in his decision-making, quite likely as a result of startle.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision making evident.

Event 13a: Partenavia P68B Fuel Starvation, 2002, Wairoa, New Zealand.

Synopsis

On 15 May 2002 at about 0918, ZK-ZSP, a Partenavia P68B, was on a scheduled flight from Gisborne to Napier when its right engine lost power because of fuel starvation. The aircraft was 5km from Wairoa, at 5000 feet and in cloud at the time. On board were four passengers and the pilot. Although the aircraft had sufficient fuel, it was not made available to the engine. The propeller was not feathered and the aircraft, unable to maintain its height, descended until it broke clear of the cloud, near the coastline. The pilot landed the aircraft safely on a metalled road. There were no injuries, and the aircraft was undamaged.

The pilot had not refuelled the aircraft at Gisborne or dipped the fuel tanks, but had calculated the fuel remaining prior to departure to be about 142 litres in the left tank and 57 litres in the right tank, sufficient for the flight. This imbalance had created some uncomfortable control loads during the flight but this was managed sufficiently by the pilot.

Shortly after the flight had crossed Wairoa NDB at 5000 feet, the aircraft's right engine suffered a substantial power loss, accompanied by a strong yaw. A PAN[11] call was made to ATC, which was upgraded to a MAYDAY[12] some 25 seconds later. The left engine was operated at full power; but the right engine, which was surging, was not shut down by the pilot, with the propeller therefore remaining unfeathered. This had the effect of creating significant drag and the aircraft was unable to maintain altitude as a result, commencing a descent. The following extract from the accident report describes the next turn of events.

> The pilot said she could not trim the aeroplane, and had to apply considerable pressure to the control column to control the aeroplane and maintain the blue line air speed. As the aeroplane descended, the pilot kept her left hand on the control column, and put her right hand on the left engine fuel selector knob positioned on the cockpit overhead panel, to select crossfeed (the opposite fuel tank). She said she could not turn the fuel selector knob and took her left hand off the control column and used both hands on the selector knob. She found the selector very stiff to operate. She selected the left engine to the right fuel tank and took control again. A short time later the left engine began to vibrate, so she realised she had selected the wrong selector knob. She again put both hands on the fuel selector knob and reselected the left engine to the left fuel tank to restore power. The pilot said she was under considerable stress during the ordeal, and each time she took her hands off the control column the aeroplane lost more height, which caused her additional stress. She said because the left engine was again running normally she elected not to attempt any further crossfeeding and to concentrate on flying the aeroplane. She still did not feather the right propeller (in accordance with standard emergency procedures), but left it windmilling. During this time the aeroplane was descending in instrument meteorological conditions (IMC). (TAIC, 2002, p. 2).

When the aircraft broke out of cloud it was approximately three miles off the coast, but the pilot was unable to determine her position in relation to Wairoa airfield and elected instead to land on a long straight road which she sighted while looking for the airport. She described concerns about the possibility of the left engine failing as contributory in her decision to land on a road rather than at the nearby airport. (TAIC, 2002).

[11] PAN is an internationally recognised radio telephony code for "urgency required"
[12] MAYDAY is an internationally recognised radio telephony code for" immediate assistance is required"

Analysis

The fuel imbalance situation in this aircraft appears to have been caused by a faulty fuel selector which had allowed some fuel to be transferred from the right tank to the left engine, despite the selector valve being in approximately the correct position. This had resulted in a large imbalance following the previous day's flying and was further instrumental in the right fuel tank running out of fuel, creating a power loss. Had the pilot selected the right engine fuel selector to the left engine at any stage, then it is highly likely that the engine would have resumed normal operation or been available for restarting.

The pilot described her demeanour during the unfolding event as very stressed and this was exacerbated by the passengers who were becoming very concerned as the aircraft descended in IMC on one engine. It is conceivable that the pilot, who was relatively inexperienced (total flight time 1403 hours, 90 on this aircraft type), was operating with elevated levels of arousal prior to the engine power loss. As a single pilot, in IMC, and with considerable difficulties in controlling the adverse effects of fuel imbalance, she was likely experiencing some effects of stress and this would have been further increased as events unfolded following the loss of power.

It is also highly likely that, while in a state of elevated stress, she would have experienced some fear-potentiated startle effects as the right engine lost power. The additional yawing moment would have also have created additional control difficulties and therefore created a considerable level of anxiety. This was evidenced by the PAN call to ATC which was very quickly upgraded to a MAYDAY call (immediate assistance required).

The pilot's decision making following the event was typical of someone who had suffered a strong startle and/or was experiencing high levels of arousal. The decision not to feather the right-hand propeller created significant windmilling drag, resulting in the aircraft being unable to maintain altitude. Had the aircraft not broken clear of cloud when it did, this lack of performance could well have resulted in the aircraft crashing as it was unable to maintain altitude. Similarly, the selection of the incorrect fuel tank selector knob was very nearly critical. By selecting the empty right tank to feed the left engine, she very nearly created a double engine failure situation and was fortunate that she reselected the correct configuration for the left tank to engine before the engine cut out completely. Finally, the decision to land on a road, when a suitable airport was very close, could be questioned.

The pilot’s underperformance following the engine failure was likely caused by elevated stress levels and compounded by the effects of a strong fear-potentiated startle.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.

Event 14a: Partenavia P68B ZK-DMA, Auckland, New Zealand, 2001

Synopsis

On Friday 20 July 2001, at around 0450, Partenavia P68B ZK-DMA was abeam North Shore Aerodrome at 5000 feet in darkness and en route to Whangarei when it suffered a double engine power loss. The pilot made an emergency landing on runway 21 at North Shore Aerodrome, but the aircraft overran the end of the runway, went through a fence, crossed a road and stopped in another fence. The pilot was the only person on board the aircraft and received face and ankle injuries. The aircraft encountered meteorological conditions conducive to engine intake icing, and ice, hail or sleet probably blocked the engine air intakes. The pilot had probably developed a mindset that dismissed icing as a cause, and consequently omitted to use alternate engine intake air, which should have restored engine power.

The following extract from the accident report describes the events.

> About a minute later, with the aircraft some 10 nautical miles north-east of North Shore Aerodrome, the pilot noticed the left engine fuel flow had dropped. The aircraft was in rain and possibly cloud at the time.
>
> The pilot adjusted the mixture control on the left engine and restored the fuel flow. A short time later the fuel flow dropped again and the engine ran rough and lost power. The pilot completed the engine trouble checks, which included turning the auxiliary fuel pump on and checking the left fuel tank was selected to the left engine. The fuel selection was not altered. The pilot said she did not select the left alternate engine intake air on because there was no evidence of ice. The pilot advised Auckland Control of the engine failure and requested vectors back to Auckland. Control directed the pilot to turn left or right onto a heading of 135°.
>
> After 23 seconds the pilot had not responded to Auckland Control, so the controller contacted the pilot. The pilot responded saying she was turning left onto a heading of 135°.
>
> About one minute and 20 seconds later the controller advised the pilot "I see you are squawking emergency". The pilot confirmed she was and said both engines were surging. During the turn onto 135° the pilot noticed the right engine fuel flow drop. The pilot completed trouble checks for the right engine, which included turning the auxiliary fuel pump on, and ensuring the mixture was rich and the right fuel tank was selected. The fuel selection was not altered from the right tank. The pilot said she did not select the right alternate engine intake air on, again because there was no evidence of ice (TAIC, 2001, p. 2).

The pilot, with some direction from ATC, eventually made a power-off descent and landing at North Shore Airport, unfortunately landing long and fast, resulting in a runway overrun. Power had not been restored to either engine during this process (TAIC, 2001).

Analysis

In this accident, it is highly likely that a double power loss was induced by intake or carburettor icing, which, given the fact that the aircraft was possibly in icing conditions, could have been predicted and prevented or rectified by the pilot concerned.

It is likely that the inexperienced pilot (total time 706 hours) may have been startled by the initial power loss on the left-hand engine. Subsequent performance may therefore have been impaired due to the initial startle and the very elevated arousal levels which would have continued. A second startle and further elevated arousal levels probably occurred as the second engine failed and the aircraft descended in cloud, at night, towards terrain. The pilot's decision not to at least cycle the alternate air as a possible trouble shooting measure was flawed and was probably a result of cognitive impairment following the initial and/or subsequent startle. In this case the failure to correctly analyse the problem, which could well have been due to cognitive impairment from the effects of startle, resulted in an aircraft accident.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.

Event 15a: Saudi Airlines Flight SV163, Aircraft Fire, Riyadh, Saudi Arabia, 19 August, 1980

Synopsis

Flight SV163 experienced a fire in the aft (C3) cargo compartment nearly seven minutes after takeoff from Riyadh, Saudi Arabia. The crew then spent some five and a half minutes trying to confirm the fire, which included the flight engineer entering the passenger cabin to observe the developing smoke and fire, before making a decision to return to the airport. The airport at Riyadh was contacted and informed that the aircraft was returning because of a fire in the cabin; the crew requested that crash, fire, and rescue (CFR) be alerted.

After commencing the turn back to Riyadh, the flight engineer returned to the passenger cabin to assess the extent of the fire, returning to the flight deck approximately 14 minutes before landing. He reported that there was just smoke in the aft end of the aircraft, however shortly after another aural smoke detector warning occurred and was recorded on the cockpit voice recorder (CVR). One minute later the captain stated that the throttle of no. 2 engine was stuck, and that he was going to shut the engine down. Also, at about this time, another flight attendant reported she could not go further aft than doors L2 and R2 because people were fighting in the aisles. This was followed by further reports from the cabin of thick smoke, and multiple passenger announcements (PA's) to the cabin to ask passengers to remain seated. Shortly before landing the captain advised the cabin crew not to initiate an evacuation after landing.

After touchdown the captain failed to stop the aircraft as soon as possible, instead rolling down the runway and onto a taxiway for some two minutes forty seconds before finally coming to a halt. Shortly afterwards the captain advised the tower that they would be shutting down the engines and evacuating, but the shutdown was not made for another three minutes and fifteen seconds. The evacuation never occurred and it took a further 23 minutes for the CFR personnel to breach the R2 door and enter the aircraft. By that time all 301 people on board had succumbed to the fire and smoke (Presidency of Civil Aviation, Saudi Arabia, 1980).

Analysis

The lack of urgency in the captain's actions in this accident was very concerning, and was indicative of a severe level of denial. The five and a half minutes it took to initiate a return to Riyadh was an exceptionally long time to be heading away from the airport with an active cargo fire warning. This suggests a level of denial of threatening information (Breznitz, 1983), a failure to accept the threatening information being presented by both the aircraft systems and the cabin crew's reports. There was also an element of denial of urgency in this critical delay. Every minute spent flying away from the airport requires an extra minute to return, which in the end may have been critical in the survivability of this incident.

Further denial of threatening information occurred prior to landing when the captain advised the cabin crew not to evacuate immediately after landing. There are very few instances where cabin crew are able to initiate an evacuation without direction; however a life-threatening and self-sustaining fire in the cabin is one instance in which this is acceptable. The fact that the captain overrode this authority, by telling them explicitly not to evacuate, meant that the cabin crew were unlikely thereafter to initiate an evacuation of their own volition.

Once on the ground there was a substantial denial of both urgency and threatening information. The fact that the captain continued to roll out and taxi off the runway for some two and a half minutes suggests that he had completely lost sight of the severe reality of the situation and the dire consequences of his actions. Had the aircraft stopped as soon as possible on the runway (which is what pilots are generally trained to do in such circumstances), and commenced an immediate shutdown and evacuation, then it is likely that at least some of the occupants may have survived.

His further delay in shutting the engines down after coming to a stop was further evidence of more denial of both urgency and threatening information. While there may have been some technical problem with the pressurisation system preventing the aircraft doors being opened for some time, the delay in shutting down the engines simply exacerbated the delay in attempting egress.

The slow taxi after landing combined with the failure to shut down the engines was likely to have been negatively consequential to situation outcome. The state of denial which allowed these delays to happen was therefore directly causal, and both were quoted in the aircraft accident report as such. The inactivity demonstrated by the crew is assessed as a denial of urgency, with a denial of threatening information also likely.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of denial. This determination is based on the following:

Underlying theme:
A pilot appears to be tactically ignoring information which could be deemed as being of significant threat to safety.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- A threatening stimulus was ignored, or the ramifications of it were ignored, in association with a period of acute stress.

- A serious or critical, and possibly deteriorating situation was unfolding, but inappropriate or no action was taken to address the problem. This was not freezing behaviour, but rather avoidance behaviour.
- The urgency of a developing situation was ignored while under conditions of acute stress.

Event 16a: VASP Flight 168, Controlled Flight into terrain, Fortaleza, Brazil, 1982

Synopsis

VASP Flight 168, a Boeing 727, had departed Rio de Janeiro for Fortaleza. As the flight approached its destination it was cleared to descend from its cruising altitude of FL330 (approximately 33,000 feet) to 5,000 feet. Flying at night, with the lights of Fortaleza in sight, the aircraft descended through its 5,000ft clearance limit and kept on descending until it crashed into a mountainside at 2,500ft, killing all 137 on board.

Investigations revealed that the captain, possibly disoriented due to bright lights from the city ahead, continued the descent well below the 5,000ft clearance limit despite being warned twice by the altitude alert system, as well as by the co-pilot, of the terrain ahead.

From the final cockpit voice recorder translated transcript:

> FO: Can you see there are some hills in front?
> [Sound of altitude alert]
> CAPT: What? There's what?
> FO: Some hills, isn't there?
> [Sound of impact] (CENIPA, 1982)

Analysis

In this accident the captain appears to have suffered some form of behavioural inaction as he continued the descent well below his clearance limit. While the first officer attempted to alert the captain to the altitude deviation and raise his concerns about the terrain ahead, the captain, who apparently had not heard or was incapable of responding to the altitude alerter warnings, continued descent 2500ft below his clearance limit.

In this case it is likely that the captain became acutely stressed as the proceedings unfolded and suffered from behavioural inaction as he became overwhelmed.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of behavioural inaction. This determination is based on the following:

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in working memory function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, no action was taken when warranted and/or expected.

Event 17a: Cessna 310 Loss of Control Inflight, Tamworth, NSW, 7 March, 2005

Synopsis

At about 1326 Eastern Daylight-Saving Time on 7 March 2005, the pilot of a Cessna Aircraft Company 310R, registered VH-FIN, took off from runway 30 Right at Tamworth Airport, for Scone, NSW. Approximately one minute after becoming airborne the pilot reported flight control difficulties. At about 1329, the aircraft impacted the ground in a cleared paddock about 7km west-south-west of the airport. The pilot was fatally injured and the aircraft was destroyed by the impact forces and post-impact fire.

Examination of the aircraft’s mechanical flight control systems, autopilot and electric trim system did not reveal any evidence of pre-impact malfunction. Those results, however, were inconclusive due to the extensive impact and fire damage. A bent hand tool found in the wreckage was not implicated in the cause of the accident.

A periodic maintenance inspection carried out in the days before the flight resulted in the rudder trim tab being set at the full right position and possibly aileron and elevator trim tabs being set at non-neutral positions prior to the flight. There were indications that the pilot was rushed and probably overlooked the rudder and aileron trim tab settings prior to takeoff. The aircraft flight path reported by witnesses was found to be consistent with the effect of abnormal rudder and/or aileron trim tab settings (ATSB, 2005).

Analysis

The final report into the accident was unable to categorically state the cause of this event, but circumstantial and evidential indications suggest that the most likely cause was the failure of the pilot to recover from the flight control effects which ensued from abnormal rudder and/or aileron trim tab settings which had likely been left set from previous maintenance.

The report suggests that the aircraft probably got airborne with full rudder trim tab set, which would have initially been manageable as the aircraft got airborne but would have become more obvious and difficult to control as the aircraft speed increased. At some stage the pilot would have had to make a cognitive decision to accept that there was a problem with controlling the aircraft, which may have had an element of startle associated with it. Startle can occur in any modality, so the sudden realisation that tactile inputs being experienced were abnormal, to the extent that flight safety was suddenly compromised, could well have engendered a fear-potentiated startle, or sudden increase in level of arousal.

The pilot commenced a left turn without clearance and advised ATC that he was having control difficulties. There was then a period of height loss, which was temporarily regained. A further turn towards the downwind was followed by a loss of control which was not recovered from.

It is conceivable and somewhat likely, that the elevated state of arousal which the pilot experienced as control became more difficult with increasing airspeed after take-off, and may well have been accompanied by a single or multiple fear-potentiated startles. His failure to recognise the source of the control input which was creating control difficulties was perhaps indicative of a pilot whose information processing, and particularly the ensuing problem-solving and situational awareness, were severely impaired. These symptoms are in keeping with research into other startle and acute stress reactions and may well have contributed to his failure to try controlling the aircraft using aircraft trim inputs.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 18a: C-5 Galaxy Landing Accident, Dover AFB, Delaware, USA, 13 June, 2006

Synopsis

Following a normal takeoff and initial climb, the C-5 aircrew observed a no. 2 engine "Thrust Reverser Not Locked" indication light. They shut down the no. 2 engine as a precaution and returned to Dover AFB. The board determined that during the return to the base the pilots and flight engineers continued to use the shut-down no. 2 engine's throttle while leaving the fully-operational no.3 engine in idle. Additionally, both instructor and primary flight engineers failed to brief, and the pilots failed to consider and use, a proper flap setting. The pilots' attempt at a visual approach to runway 32 resulted in the aircraft descending well below a normal glidepath for an instrument-aided approach or the normal visual flight rules pattern altitude and the aircraft stalled and crashed into a field about a mile short of the runway (US Air Force, 2006).

Analysis

As the aircraft climbed out of Dover AFB on its way to Ramstein AFB in Germany, the crew received a warning that the no. 2 engine thrust reverser was not locked. Had the engine actually transitioned into a reverse thrust mode then it is highly likely that it would have become uncontrollable, so it is likely that the crew of this aircraft understood the implications of this warning and were startled and suddenly highly aroused by its appearance.

The crew took the correct actions of shutting down the no. 2 engine and then hurriedly returned towards Dover for a return to land at high weight. It appears that only limited briefings were conducted or consideration given to an appropriate flap setting and other possible threats or operational complexities.

During the approach to land the crew inadvertently started manipulating thrust levers 1, 2 and 4, instead of 1,3 and 4. In doing so, no. 3 engine’s thrust lever was inadvertently left at flight idle, effectively reducing the aircraft to a two-engine situation. Once the aircraft was fully configured with gear and flap, this reduced thrust then became insufficient for the aircraft to maintain profile and the approach was continued to a crash landing well short of the runway.
It appears that the crew, who were suddenly confronted with a potentially life-threatening emergency on departure, displayed some severe breakdowns in information processing typical of that following startle and high levels of autonomic arousal. Their rush to return without fully briefing and giving full consideration to all the possible threats and complexities may well have been induced by startle and the ongoing high levels of arousal. Similarly, the misuse of the engine thrust levers and the failure to commence a go-around (plan continuation bias) are suggestive of elevated arousal and the possibility of some denial processes.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual or tactile modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.

Event 19a: Air Canada Flight ACA878 upset when FO wakes up from crew rest

Synopsis

An Air Canada Boeing 767-333 was enroute from Toronto to Zurich in the mid-Atlantic when the first officer began a period of controlled rest. At 0155, the captain made a radio call which woke the first officer after 75 minutes of sleep. Simultaneously, an opposite-direction United States Air Force Boeing C-17 at 34 000ft appeared as a TCAS target on the navigation display. The first officer initially mistook the planet Venus for an aircraft but the captain advised him that the target was at the 12 o'clock position and 1000ft below. Moments later, when the first officer saw the oncoming aircraft, he interpreted its position as being above and descending towards them. The first officer reacted to the perceived imminent collision by pushing forward on the control column. The captain, who was monitoring the TCAS target on the Nav Display (ND), observed the control column moving forward and the altimeter beginning to show a decrease in altitude. He immediately disconnected the autopilot and pulled back on the control column to regain altitude. It was at this time the oncoming aircraft passed beneath ACA878. The TCAS did not produce a traffic or resolution advisory, however during the pitch excursion, the aircraft pitch changed from the cruise attitude of two degrees nose up, to six degrees nose down followed by a return to two degrees nose up. The vertical acceleration forces (g) went to -0.5 g then to +2.0 g in five seconds. Airspeed also increased seven knots, then decreased 14 knots, before recovering to cruise speed with the aircraft's altitude decreasing to 34,600ft, before increasing to 35,400ft and then finally recovering to 35000ft. Fourteen passengers and two flight attendants were injured (TSB Canada, 2011).

Analysis

In this case the first officer had been asleep for 75 minutes when he was woken by a radio call from the captain. While the controlled rest period he took was a recommended mitigation procedure for fatigue, it was considerably longer in duration than the 40 minutes allowed by Transport Canada's and Air Canada's regulations. In so doing, it is quite possible that he entered a phase of deep or slow wave sleep (Gander, 2009), and as a result was more prone to a phenomenon known as sleep inertia when he woke up (Gander, 2009). Sleep inertia is a transitional state of lowered arousal occurring immediately after awakening from sleep which can produce a temporary decrement in subsequent performance (Tassi & Muzet, 2000).
While little research is available regarding the effects of startle during sleep inertia phases, research has shown that people who are tired are more susceptible to pronounced startle effects (Simons, 1996). In this case it is highly likely that the effects of sleep inertia impaired the ability

of the first officer to integrate the information presented by the captain and what he was seeing visually. When he acquired the lights of the other aircraft he perceived that it was above him and descending towards him, creating a strong startle response. He reacted by disengaging the autopilot and pushing over in a perceived evasive manoeuvre, before the Captain could assume control and reinitiate a climb away from the traffic which was in fact below them.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the visual modality was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.

Event 20a: Air Blue Circling Approach Islamabad, 2006

Synopsis

Flight ABQ202 had departed Karachi International Airport on a domestic service to Islamabad, Pakistan. Weather at Islamabad was poor with deteriorating visibility. A Pakistan International Airlines (PIA) flight had landed on the third attempt and a flight from China had diverted. ABQ202 was cleared for a Runway 12 circling approach procedure. During the approach the captain descended below the minimum descent altitude (MDA) of 2,510ft to 2300ft, losing visual contact with the airfield. The captain then decided to fly a non-standard self-created approach based on Place-Bearing-Distance (PBD), in so doing transgressing out of the protected airspace by a distance of 4.3 nm into the Margalla Hills area.

The captain did not take appropriate action following calls from ATC. He also did not respond to 21 EGPWS warnings related to approaching rising terrain, resulting in the aircraft flying into the side of a mountain.

The following extracts from the accident report provide an analysis of the events on the accident flight:

> In an attempt to turn the aircraft to the left, the captain was setting the heading bug on reduced headings, but not pulling the HDG knob. Since the aircraft was in the NAV mode, the captain was not performing the appropriate actions to turn the aircraft to the left.
> At 0440:28, lateral mode was changed from NAV to HDG, 40 Seconds before the impact. At this stage, current heading of aircraft was 307 degrees, whereas selected heading had been reduced to 086 degrees, due to which the aircraft started to turn the shortest way to the right towards Margalla hills by default. From that time onward, several EGPWS predictive "TERRAIN AHEAD PULL UP" warnings were recorded on the CVR until the end of the flight.
> The aircraft had ended up in a dangerous situation because of most unprofessional handling by the captain. Since the desired initiative of FO had been curbed and a communication barrier had already been created by the captain, the FO failed to intervene, take over the controls to pull the aircraft out of danger and display required CRM skills.
> At 0440:30, [the] FO stated to the captain twice in succession "Sir turn left, Pull Up Sir. Sir pull Up".
> At 0440:33, the thrust levers were moved forward to the MCT/FLX detent (instead of TOGA position) and the auto-thrust (A/THR) disengaged.
> At 0440:35, the selected altitude was changed to 3,700 ft and the aircraft started to climb. The aircraft was still turning right.
> At 0440:39 (within 06 seconds), the thrust levers were moved back to the CLB detent and the A/THR re-engaged in climb mode. The selected altitude was reduced to 3100 ft.
> At 0440:41, FO stated to the captain yet another time "Sir Pull Up Sir".
> At 0440:46, autopilot 1 was disconnected. The roll angle was 25° to the right. The captain applied full left side stick along with a 6° left rudder pedal input and the aircraft started to turn left. The altitude was 2,770 ft and increasing.

During the last few seconds, the aircraft did climb to 3,090 feet. The Captain put in 52 degrees of bank to turn the aircraft, and also made some nose down inputs. Therefore, the aircraft pitched down, speed increased and auto thrust commanded the engines to [spool] down to keep airspeed on the target speed. The aircraft started again to descend at a high rate.

Until 0440:46 the captain continued to move the HDG bug without actually looking at it, but failed to pull the knob to activate it. When he did activate it, the aircraft turned towards the HDG bug that had been rotated overly to 025 Degrees until end of recording, and at 0440:49, captain said to FO "left turn kiun naheen ker raha yar?" (Why the aircraft is not turning to left?). 8.49 At 0440:52 the captain started to make pitch down inputs. The roll angle was 30° to the left. The pitch attitude was 15° nose-up and started to decrease.

At 0440:58, the altitude reached 3,110 ft and started to decrease until the end of the flight.

At 0441:01 an EGPWS reactive "TERRAIN TERRAIN" warning was recorded on the CVR. The roll angle reached its maximum value of 52° to the left.

At 0441:02, FO said "Terrain sir". The pitch attitude was 4.6° nose-down.

At 0441:03, the captain started to make pitch-up inputs. The pitch attitude was 3.9° nose-down.

At 0441:05, an EGPWS reactive "PULL UP" warning was recorded on the CVR.

At 0441:06, the FO was heard the last time saying to captain "Sir we are going down, Sir we are going da".

The high rate of descend at very low altitude could not be arrested and the aircraft flew into the hill and was completely destroyed. All souls on board sustained fatal injuries due to impact forces (Pakistan Civil Aviation Authority, 2007, p. 26).

Figure 32 shows the ground track of the aircraft.

Image removed

Figure 32 – Flight ABQ 202 Flight Path
(Pakistan Civil Aviation Authority, 2007)

Analysis

The captain on this flight was likely suffering from an elevated state of arousal, probably from the time he became visual with the ground at the bottom of the ILS, when, in fairly atrocious weather, an aircraft from an opposing airline landed safely. The weather conditions in the circling area were very poor with low cloud and poor visibility and the captain almost immediately breached the circling minima by descending to 2300ft (over 200ft below the MDA). Rather than fly a bad weather circuit, remaining in visual contact with the ground below and the runway off to the left, the captain then elected to fly the remainder of the flight using a predetermined flight path, which utilised a series of PBD waypoints he had constructed in the standby flight plan earlier. This flight path created a circling approach with a downwind leg which was five nautical miles from the runway, outside the surveyed circling area and over higher terrain. The secondary plan also encroached on an active Danger Area[13] and a no-fly zone, which ATC eventually advised them to steer clear of.

When the first EGPWS warning "Terrain Ahead" went off, it is probable that the captain, already in an elevated state of arousal as he fought to see ahead, suffered a fear-potentiated startle. Following the initial EGPWS warning the captain displayed behaviours which were

[13] Danger Areas are advised to pilots via Notices to Airmen. They contain hazards which must be avoided.

typical of startle and his lack of comprehension as to why the aircraft would not turn left when he was turning the heading knob suggests some cognitive disruption. When he did finally engage HDG mode some 12 seconds later he then became very confused again as to why the aircraft had started a right turn when he wanted it to go left.

When the first EGPWS hard warning of " Terrain Ahead, Pull Up" occurred at 0440:28, it is likely that the captain, in a very high state of arousal, suffered another fear-potentiated startle, with further effects on his cognitive and psychomotor abilities. From this point on he made several attempts to climb and turn the aircraft, and perhaps attempted to escape from terrain by advancing the thrust levers. Unfortunately he only selected MCT/FLX thrust and not full thrust as the normal terrain escape manoeuvre requires, and he made several changes to the altitude selector, none of which would have cleared the terrain ahead. During this time the aircraft pitch varied substantially and bank angle varied wildly, swinging from 25° right roll to 52° left roll. Despite repeated calls from the FO and several hard EGPWS warnings, the captain never adequately commenced the terrain escape manoeuvre and the aircraft eventually impacted terrain at 3090 feet above mean sea level (AMSL).

There is evidence that the captain was in a very high state of arousal and, following the first EGPWS caution made several procedural, manipulative and other errors. He appears to have had severe impairments to his level of situational awareness and continued to make poor decisions. It is highly likely that his elevated state of arousal, coupled with two or more instances of fear potentiated startle, impaired his performance significantly, which in turn led to the aircraft crashing into high terrain.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.

- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 21a: Metro III Loss of Control Inflight, Tamworth, Australia, 16 September, 1995

Synopsis

This flight was the second Metro III type conversion training flight for the first officer, having earlier in the evening completed his first, 48 minute, training flight. The check and training (C&T) captain briefed the first officer that he would give him a V1 cut (simulated engine failure at decision speed) during the takeoff, then the crew briefed the instrument approach procedure which would follow the departure. No information was provided by the check and training captain on "how" to fly the aircraft in an asymmetric condition.

With the first officer conducting the take-off, the aircraft became airborne and the check and training captain retarded the left power lever to flight idle four seconds later to simulate an engine failure. Some 11 seconds later, the first officer prompted the C&T captain with a call of "positive rrr…" (rate), to which the captain then replied "yeah positive rate yeah". ("positive rate" is the prompt for the first officer to call for the landing gear to be raised.) The delay in raising the gear, on only one engine, had a significant impact on the ability of the aircraft to climb. Inappropriate control inputs from the first officer also contributed to a deterioration in the performance of the aircraft; however, this was either not recognised by the C&T captain or ignored. The captain never intervened to terminate the exercise and the aircraft crashed 39 seconds after takeoff.

The following is an extract from the CVR Recording from the accident recording:
(Note: C&T = check & training captain; CP = co-pilot/first officer)

1957.30	C&T	vee one, rotate
1957.33	C&T	just ten degrees Edward. yeah
1957.38	C&T	I think we've got an engine failure
1957.39	CP	yep

1957.41	C&T	set max power eh
1957.41	CP	are you gonna
1957.42	CP	set oh sorry set max power
1957.43	C&T	yep you got it
1957.44	CP	positive rrr
1957.45	C&T	yeah positive rate yeah
1957.46	CP	gear up thanks
1957.47	C&T	yeah//sound of gear warning horn starts//
1957.50	CP	it's the ah left engine
1957.51	C&T	vee two thanks
1957.53	CP	left engine
1957.54	C&T	just don't lower the nose too much. don't fight it
1957.55	C&T	that's it. yair left engine weve got no egt and low fuel flow there
1958.00	CP	(ar.. then) we'll ah feather the left then thanks
1958.02	C&T	ok vee two thanks hold vee two
1958.05	C&T	were descending. feather the left one. ok it's feathered
1958.06	// sound of gear warning horn stops //	
1958.07	//non pertinent words // // sounds of impact//	
1958.09	Recording ends. (BASI, 1997, p. 56)	

The accident report makes specific commentary about the performance of the check and training captain. The following extract discusses these issues.

> The CVR evidence strongly suggests that the check-and-training pilot had lost awareness of the position and performance of the aircraft. It indicates that his concept of time had been reduced. Examples of this include:
>
> (a) His failure to prompt the call for the landing gear to be retracted before the co-pilot called "positive rrr" (1957.44).
>
> (b) The retraction of the landing gear 11 seconds after the power lever was retarded. Extension of the landing gear for this period would have had a significant effect on aircraft performance.
>
> (c) Recorded comments on the CVR by the check-and-training pilot indicated that he was aware that the co-pilot was having difficulty in controlling the aircraft and attaining and maintaining V2. These comments extended from 19 seconds to 30 seconds after the aircraft became airborne, yet the check-and-training pilot continued

to go through the checklist actions and made no apparent attempt to take control of the aircraft.

(d) Other than to move the left engine power lever forward at least sufficiently to cancel the landing gear warning horn, there was no other reaction by the check-and-training pilot when he called "we're descending" 2 seconds before the aircraft struck the tree. (ATSB, 1997, p. 43).

Analysis

While this accident had its roots in an organisational culture which allowed type rating training, including simulated engine failures after takeoff, at night, the performance of the C&T captain was of concern.

In this instance the relatively inexperienced C&T captain failed to monitor the actions of the very inexperienced pilot under training, and furthermore, never adequately monitored the aircraft's flight path with respect to terrain. More importantly, he never assumed control or restored power, which indicates that his conceptualisation of the unfolding events was impaired.

The operating crew of the aircraft were both, in all likelihood, in an elevated state of arousal prior to takeoff. The first officer, having only flown the aircraft for 48 minutes previously, was still coming to grips with the handling of a demanding aircraft, and expressed concern about the simulated engine failure training at night in the aircraft. His inexperience on type, coupled with the anticipated difficulty of the exercise ahead, very likely created a fair amount of stress in him. This was compounded by a poor briefing, in which the C&T captain gave very little guidance on how to manage the flight path following engine failure after take-off. As a result the flying pilot's arousal state was probably very high, especially following the failure, where his limited time on type, coupled with an extremely demanding manoeuvre, created a situation which was probably beyond his capabilities at the time. It is quite possible also that the actual V1 cut, when the captain suddenly retarded the power lever, spiked his arousal level, possibly startling him in the process, with ensuing performance impaired further by the cognitive and psychomotor deficits induced by this startle.

The captain likewise, having had no experience at training in the aircraft at night, was probably in an elevated arousal state prior to take-off and may have himself been impaired by an element of startle as he retarded the power lever to the stop, with the ensuing poor performance creating concern. This perhaps manifested itself with some behavioural inaction as he neglected to prompt the gear retraction with a positive rate call for some 11 seconds. This lapse, coupled with a lower than optimal power setting on the simulated failed engine, probably contributed strongly to the substandard performance of the aircraft. When the gear was finally raised, the gear warning horn, which started immediately, may also have created some startle in one or both pilots. The subsequent inability of the first officer to accurately fly the aircraft (which wasn't surprising given his experience) should have been the primary focus of the C&T captain, but his attention became focused instead on completing the failure drills. Had the captain attended to the deteriorating flight path and taken appropriate steps to restore sufficient power to climb away, the accident may have been avoided. It is also possible that his decision-making was impaired by the startle and ongoing elevated levels of arousal which manifested as a lack of corrective action.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.

Event 22a: Air France Flight 358, Runway overrun, Toronto, Canada, 2004

Synopsis

While on final approach to Toronto, the flight crew was advised that the crew of an aircraft landing ahead of them had reported poor braking action, and Air France Flight 358's aircraft weather radar was displaying heavy precipitation encroaching on the runway from the northwest. At about 200ft above the runway threshold, while on the ILS approach to Runway 24L with autopilot and autothrust disconnected, the aircraft deviated above the glideslope and the groundspeed began to increase. The aircraft crossed the runway threshold about 40 ft above the glideslope. During the flare the aircraft travelled through an area of heavy rain, and visual contact with the runway environment was significantly reduced. The aircraft touched down about 3800 ft down the runway, reverse thrust was selected about 12.8 seconds after landing, and full reverse was selected 16.4 seconds after touchdown. The aircraft was not able to stop on the 9000-foot runway and departed the far end at a groundspeed of about 80 knots. The aircraft stopped in a ravine and caught fire (TSB Canada, 2005).

Analysis

This accident came about due to multiple factors. The aircraft, which was initially stabilised on approach, ran into a wind shift which caused it to become slightly high and slightly fast. This caused the aircraft to float in the flare, eventually touching down some considerable distance into the runway. The runway was wet and the visibility had reduced significantly in a heavy shower, but the principal concern was the lack of reverse thrust, which was not selected for some 12 seconds after landing. The captain, who was PM, did not make the standard calls regarding spoilers and thrust reverser status after landing, which likely contributed to the delay in reverse selection.

In examining the cause of the thrust reverser delay, evidence suggests that as the aircraft started to float down the runway further and further, and as visibility reduced, the level of arousal in both pilots would have started to increase as their appreciation of runway remaining, experiential assessment of risk, and the increased complexity caused by the poor visibility suddenly encountered, started to induce stress. By the time the aircraft touched down 42% of the way down the runway, the flight crew would have been aware that they were in a critical position, which would have created substantial levels of arousal.

The CVR transcript for this accident was not made available by Transport Canada as part of the accident report. This makes it impossible to determine what was happening during the 12.8 seconds from touchdown to reverser deployment; however it is clear that there was a substantial period of inaction in relation to normal procedures by both the first officer and the captain.

This behavioural inaction was most likely an acute stress reaction brought on by the criticality of the situation which had developed and was increasingly realised by both pilots. One of the by-products of acute stress, well known in the literature, is a concept called “perseveration”

(Stokes & Kite, 1994), in which people under stress continue with the current plan regardless of whether it is the best one. Had the crew been acutely stressed, then this ongoing perseverance with the decision to land, even while the aircraft was floating substantially into the runway, coupled with the behavioural inaction once on the ground, would be typical of acute stress reactions noted in the literature.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of behavioural inaction. This determination is based on the following information.

Underlying theme:
Behavioural inaction resulted from exposure to some overwhelming stimuli, which were not startling, but involved a degree of threat and were likely to be acutely stressful.

Specific criteria:

- An acutely stressful situation developed, or was likely perceived as developing, but without the presence of a surprising stimulus.
- There was evidence of highly elevated arousal levels. This evidence manifested itself in breakdowns in WM function, in distraction, in target fixation, in perseverance, in degraded vigilance, or in poor decision-making.
- While under conditions which are likely to be conducive of acute stress, there was no action taken at a time when action was warranted and/or expected.
- A pilot stopped responding and/or failed to take appropriate action, to the point where another pilot was forced to take control.
- A pilot froze on the controls to the point where some physical action was necessary for another pilot to take control.

Event 23a: SAAB 340B, VH-OLM, Inflight Loss of Control due to Airframe Icing, 28 June 2002

Synopsis

The aircraft was making an approach to Bathurst Airport in New South Wales, Australia. Icing conditions had been encountered during the descent and ice had accumulated on the wings of the aircraft, which led to an unannounced stall occurring at a height of 1264 feet above ground level (AGL). The aircraft was finally recovered at 112 feet AGL after a series of violent rolling and pitching manoeuvres.

The following extract from the accident report describes the events:

> At 1830:09, the flight crew levelled the aircraft off at 3,712 ft AMSL. The recorded speed was 135 KIAS, with engines 1 and 2 torques at 15 per cent and 19 per cent respectively. The radio altitude was 1,272 ft AGL and the OAT was recorded as 2°C.
> At 1830:11, with a recorded speed of 133 KIAS and a radio altitude of 1,264 ft, the aircraft commenced a right bank into a turn in response to aileron deflection. This was likely as a result of pilot input to the autopilot.
> The aircraft attained 28 degrees right roll at 1830:17, with an angle of attack of 8.9 degrees and speed of 116 KIAS.
> Approximately 1 second later, at an angle of attack of 12.35 degrees and speed of 114 KIAS the aircraft commenced a roll back to the left in response to autopilot driven aileron deflection and the engine torques were increased through 28 per cent.
> An angle of attack of 12.55 degrees was recorded 1 second later. The speed at this time was 113 KIAS, pitch angle 10 degrees noseup. The left roll continued through 8 degrees right bank and the engine torques continued to increase through 38 per cent.
>
> An uncommanded left roll then commenced, with the aircraft rolling rapidly and reaching 109 degrees left bank at 1830:23. At this time the speed was 109 KIAS, the engine torques had decreased through 34 per cent and the aircraft began pitching nose down through 7 degrees.
> The pilot responded with aileron input to roll the aircraft back to the right. At 1830:24 the aircraft began descending with an increasing nose-down attitude and 90-degrees left bank.
> The aircraft was descending through 3,488 ft (estimated 960 ft AGL) at 1830:26 when it attained its maximum nose-down pitch of 27 degrees; engine torques at this time were 51 per cent.
> At 1830:28 the autopilot disengaged when the angle of attack increased from 12.02 degrees to 16.22 degrees. The aircraft was passing through 3,216 ft AMSL (estimated 688 ft AGL), rolling back to the right and travelling at 146 KIAS in a 19 degrees nose down attitude.
> During the following 3 seconds the aircraft descended a further 336 ft to 2,880 ft AMSL (estimated 352 ft AGL), while rolling right through wings level to 56 degrees right wing

low. Both ailerons were simultaneously in the maximum positive position (trailing edge up) of 27 degrees (left) and 29 degrees (right) for this period (see para 1.16.1).

During the following five seconds the aircraft continued to descend, rolling back to almost wings level and nose-up pitch in response to pilot commands. The engine torques increased towards 100 per cent and a vertical acceleration of +2.56g was recorded. The minimum altitude during the stall recovery was recorded at 1830:36. The altitude AMSL was 2,640 ft, 112 ft AGL and speed 165 KIAS.

The aircraft then began to climb with the crew retracting the landing gear at 1830:39 and retracting the flaps about one minute later, before a missed approach procedure was carried out.

Following the stall, the aircraft descended approximately 1,072 ft in 13 seconds prior to regaining altitude. The radio altitude data, although recorded, was erratic during this period due to the excessive pitch and roll angles of the aircraft.

During most of the stall recovery, the autopilot entered the command cutout mode in the different axis due to the high angular rates and pitch and angle of attack angles. The PIC overpowered the autopilot rolling the aircraft back from 109 degrees left bank, to a left bank angle of approximately 35 degrees, when due to high angle of attack, ice accumulation on the wing leading edges and the continuing roll rate to the right, the right wing stalled, rolling the aircraft to about 56 degrees to the right. During this second stall, the stick shaker / stall warning system was most probably activated and consequently the autopilot disengaged. The manufacturer's analysis showed that during the second stall, both pilots probably were steering their respective control wheels, but due to the stalled outer right wing, together with different directions of the control wheel input by the two pilots, the aileron spring unit opened up shortly after the second stall, resulting in both aileron's trailing edges deflecting fully upwards. As soon as roll rate to the left was achieved, the PIC most probably relaxed somewhat on the control wheel force and together with gradual changes of the aileron hinge moments, the spring unit returned to normal position. The flight crew regained control of the aircraft and commenced a go-around and uneventful landing. (ATSC, 2003, p. 2)

Analysis

This incident happened as the result of several factors. The combination of airframe ice accretion, which increased the aircraft stall speed, the failure of the PF to increase power when levelling out, which led to reducing airspeed, and the use of full bank when turning downwind all contributed to the aircraft stalling without warning from approximately 1200 feet AGL.

The crew was unexpectedly presented with a critical event, with the aircraft suddenly entering a violent rolling and descending manoeuvre. As the roll reached 109° left, it appears that both the captain and first officer were independently trying to roll the aircraft back to the right with the autopilot still engaged. It is highly likely that fear-potentiated startle would have been experienced by both pilots, resulting in a full arousal of the sympathetic nervous system, including the introduction of adrenaline into the bloodstream. This boost of adrenaline would have assisted both crew members to override the autopilot, which was still engaged, although the disparity between the two pilots' actions did result in the aileron tie system disengaging. This resulted in the pilots retaining independent control of their respective ailerons thereafter.

As the pilots instinctively tried to fight the rolling and pitching moments that occurred as first the left then right wings stalled, two things were worthy of note. Full power (generally in the vicinity of 110-115% torque) was not applied at any stage and 100% torque was only applied very late in the process. The immediate application of full power is the first action in the manufacturer's quick reference handbook (QRH) for stall recovery and was not carried out until at least eight seconds after the initial roll. The second thing of note was that the pilots never disconnected the autopilot. It only disconnected automatically when the aircraft stall warning system sensed a stall condition, approximately five seconds after the initial roll onset. This occurred at an angle of attack of approximately 16°, which indicates that the pilots were probably not trying to lower the nose, which is the other principal means of stall recovery.

It is very likely that the crew of this flight suffered a very strong startle. They were surprised by a sudden, life-threatening, critical event and were very fortunate to recover the aircraft around 100 feet above ground level.

Determination of Pathological Behaviour

The behaviours exhibited by the captain and first officer are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.

- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 24a: Independent Air 1851, Boeing 707, Controlled Flight Into terrain, Azores, 8 February, 1989

Synopsis

The aircraft hit a mountain top while attempting to land at Santa Maria in the Azores. The crew mistakenly continued to descend through 3,000 ft, the altitude to which ATC had cleared it. Because of an overlap in communications, the tower did not notice the mistake and the aircraft continued to descend while battling some strong turbulence. It levelled at 1735 feet before running into a ridge on top of Pico Alto Mountain. Prior to impact the GPWS warning "Whoop whoop pull up" sounded continuously for seven seconds, but there was no comment or reaction from any crew member. All 144 aboard were killed. The following is a transcript of the final moments of the flight from the CVR.

14.06:57	CAM-1	We are level at two.
	CAM-2	Yeah.
	CAM-1	-- To the left.
	CAM-1	(At eight DME)
	CAM-?	() Cliffs.
	CAM-?	Yeah.
14.07:34	CAM-2	Starting to pass throughout layers here.
14.07:52	CAM-1	Can't keep this SOB thing straight up and down.
14.07:57	CAM-2	() Help you.
	CAM-1	No.
	CAM-?	()
	CAM-?	()

	CAM-?	[Sound of radio altimeter]
14.08:05	GPWS	Whoop whoop pull up Whoop whoop pull up Whoop whoop pull up Whoop whoop pull up
14.08:12		[Sound of impact]”

(Duke, 1995, p. 6; planecrashinfo, nd)

Figure 33 shows the flight profile up to the accident. Of note is that the aircraft remained level at 1735 feet while the GPWS warning was sounding.

Image removed

Figure 33 – Flight Profile of Independent 1851

(Duke, 1999)

Analysis

The aircraft impacted a ridge on top of a hill and would have avoided disaster had the crew simply pulled up a few feet. Duke (1995) suggested that median time to react to a GPWS warning from airline data is about 5.4 seconds, so the crew had sufficient time to try and recover this situation. The fact that no action took place was unfortunate; however, it is not atypical of pilots who are suddenly confronted with an immediate and unexpected critical situation.

The most likely reason why the crew of this flight failed to take any action following the GPWS warning is that they were suddenly and unexpectedly presented with an unexpected stimulus (GPWS warning: “Whoop whoop pull up”) which would likely have caused a very strong, fear-potentiated startle. Research has shown that the onset of such a stimulus can have significant effects on information processing and on psychomotor performance for some seconds afterwards. Had this been the case then the crew may well have been impaired to the point that they were still trying to integrate this new stimulus into their mental model of what was happening and were unable to put into action their practised routine of the terrain escape manoeuvre, which would have been practised during initial and ongoing training.

Determination of Pathological Behaviour

The behaviours exhibited by the crew are assessed as typical of startle. This determination is based on the following information.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 25a: Kenya Airways B737-800, Loss of Control Inflight, Douala, Kenya, 5 May, 2007

Synopsis

On a night departure from Douala International Airport to Nairobi, the Kenyan Airways B737-800 climbed to about 1000 feet before starting a slow right roll that increased in severity and was never recovered from. The aircraft entered a spiral dive and crashed in a mangrove swamp. The problem started when the captain erroneously assumed that the autopilot had been engaged at 1000 feet after take-off. The following extracts from the CVR describe the events:

0006:41: The captain calls “OK COMMAND”; The FO does not respond

[pieces of the transcript removed for brevity from 0006:41 – 0007:19]

0007:19: The bank angle aural warning sounds: “BANK ANGLE”. The roll control wheel is immediately turned 22° to the right, then 20° to the left, again 45° to the right and finally 11° to the left. The bank angle increases rapidly to the right.

0007:23: at 2770 feet, without any call, the “CMD A” mode of the autopilot (AP) is engaged;

Action on the flight controls decreases; some action on the right rudder pedal is perceptible; the bank angle, which reaches 50°, tends to stabilise.

0007:28: Intense action on the flight controls resumes; first roll movement to the right, then to the left and again to the right. Several bursts of rudder inputs are made to the right. The captain announces “we are crashing”. The FDR indicates:

- Altitude 2800 feet
- Pitch angle +5°
- Speed 220 kts
- Bank angle: 55° to the right and increasing rapidly

0007:29: Uncoordinated movements of the flight controls increase, coupled with bursts of right rudder applications. The FO confirms: “right, yeah we are crashing right”. The bank angle reaches 70° to the right.

0007:31: Prolonged pressure on the right rudder pedal is perceptible while the roll control wheel is moved from left to right and then completely to the left. The FDR indicates:

- Pressure altitude 2900 feet and decreasing rapidly
- Heading 290°
- Pitch angle minus 3°
- Speed 220 kts
- Bank angle 80 ° to the right, and increasing rapidly.

007:33: The FO calls “Right captain, Left, Left, Left…..correction Left ###***. The DFDR indicates:

- Pressure altitude: 2700 feet, in a dive

- Heading: 330°
- Bank angle: 90° to the right

0007:35: The bank angle reaches 115°, then decreases towards 70°, following full left roll input on the control wheel.

- The altitude is 2500 feet
- The heading reaches 360°
- Other bursts of roll inputs on the control wheel and some pressure on the right rudder pedal are perceptible.

0007:40: The altitude is 1300 feet; the bank angle is 70°; the speed is 270 kts

0007:42: The airplane crashes with speed of 287 knots, a pitch angle of minus 48°, heading 090°, and 60° right bank angle. (Kenyan Department of Transport, 2008, p. 15).

Analysis

The circumstances of this accident were founded in poor team coordination on the flight deck. The misunderstanding between the captain and first officer that the other had engaged the autopilot led to a situation where, certainly the captain at least, initially believed the autopilot to be engaged, while the aircraft commenced a slow roll to the right. This was not picked up by the captain due to a lack of instrument scan and black hole conditions outside which provided no visual reference.

When the first "BANK ANGLE" warning went off, it is quite likely that the captain was suddenly confronted with an unexpected situation. He reacted by making random, opposing control inputs, which exacerbated the problem. His unannounced attempt to engage the autopilot appears to have been momentarily relieving but inevitably unsuccessful, and he continued making coarse and uncoordinated control inputs thereafter to try and control the aircraft. Throughout this process it appears that he failed to use the artificial horizon information available to him on his primary flight display, and the state of the aircraft continued to deteriorate until it crashed in an uncontrolled spiral dive.

It is highly likely that the captain was initially startled by the "BANK ANGLE" call. This unexpected and disturbing event probably created a condition of elevated arousal associated with a fear-conditioned startle as he randomly rolled the aircraft left and right trying to make sense of the situation he was suddenly confronted with. His comments "we are crashing" just nine seconds after the first bank angle warning would tend to indicate that his state of arousal was very high and that he feared for his life.

Research shows that information processing can be severely impaired following a strong startle and it is likely from the evidence presented that the captain at least was in an acute state of stress, probably in conjunction with the ongoing after effects of a strong startle, induced by an unexpected critical event.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following:

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 26a: Swissair Flight 111 Inflight Fire and Loss of Control Inflight, 1998

Synopsis

On the 2nd of December 1998, a Swissair MD-11 departed JFK Airport in New York bound for Geneva, Switzerland. While in the cruise at FL330 (approximately 33,000 feet), about 50 minutes after departure, and abeam Halifax, Nova Scotia, some arcing in electrical wiring in the rear of the flight deck created a small fire accompanied by smoke. The crew initially made an assessment that the smoke was from an air conditioning source; however, there was initially no major concern over the severity of the smoke. Some four minutes later, however, the flight crew issued a PAN call and requested a return to Boston Airport, some 300nm away (despite Halifax being only 56nm away). The aircraft commenced a turn back towards Boston and started a descent to 10,000 feet, with the pilots then donning their oxygen masks as the amount of smoke started to increase significantly.

Shortly after the turn towards Boston the ATC asked the crew whether they would prefer to go to Halifax, which they accepted, and started tracking in that direction. ATC then cleared the aircraft to descend to 3,000 feet, although the crew declined this, asking for an intermediate altitude of 8,000 feet to wait for the cabin to be readied. The crew also asked for some additional track miles to lose some altitude, resulting in the Controller vectoring them towards the north. Some ten minutes after the first indications of smoke, the crew then decided that they needed to dump fuel to lower the aircraft's weight for landing (despite certification which allows the aircraft to land overweight during emergencies). The crew then agreed to a turn to the south (away from the airport) to dump fuel and continued descent to 10,000 feet, delaying the dump until clear of the coast.

The controller then advised that he would keep the aircraft within 35-40nm of the airport, which was accepted by the crew. At that stage they hadn't commenced fuel dumping but sought ATC advice on when that would become possible. Some 20 seconds later the crew advised that they needed to fly the aircraft manually (due to failure of the autoflight systems) and requested an altitude block from 9,000 to 11,000 feet. This was quickly followed by a mayday call and advice from the crew that they were starting to dump fuel. The crew then indicated that they needed to land immediately, however the controller advised that he would get back to them "in a couple of miles". Shortly after this the crew declared another emergency to which the controller responded with a clearance to dump fuel some 14 seconds later. There was no response to this transmission and no subsequent communications from the crew. The aircraft impacted the sea near Peggy's Cove some five minutes later (TSB Canada, 2001).

Analysis

This accident occurred due to an inflight fire which started in a panel in the rear overhead area of the flight deck. The fire initially manifested itself as a small amount of smoke, which the crew mistook for smoke from an air conditioning source, however it quickly increased in intensity and eventually filled the flight deck with smoke and flames.

There were several iterations of denial in this accident. In the first instance, the crew, who were faced with smoke on the flight deck, decided that the situation was serious enough to divert but elected initially to head for an airport some 45 minutes away. This suggests an element of denial, in which the threat of environmental cues is dismissed as being non-urgent. Breznitz (1983) called this type of behaviour "denial of urgency", and this situation continued to manifest itself and to increase in severity at various times throughout the remainder of the flight. The second iteration occurred when the crew, who were on oxygen and faced with a substantial amount of smoke on the flight deck, declined an offer to descend to 3,000 feet, deciding instead to accept an intermediate altitude of 8,000 feet while they waited for the cabin to be readied. This suggests a strong element of "denial of threatening information" was prevailing at this time (Breznitz, 1983).

This was followed shortly after by another iteration of denial when the crew, who were authorised to land overweight, decided that they should dump fuel to reduce weight prior to landing. This involved a turn away from the airport and some delay as the aircraft tracked towards a suitable area for fuel dumping. This strongly suggests that the threatening information, which must have been abundantly salient, was being denied by both pilots. Their lack of urgency in getting the aircraft on the ground, despite a severe fire and thick smoke on the flight deck, accompanied with failing aircraft systems, suggests that they were clearly in some form of denial regarding their predicament.

In the end, the delays caused by the denial of both urgency and the threatening information contributed strongly to the crew being overcome by overwhelming smoke and fire on the flight deck. There is no guarantee that had the crew elected to land immediately at Halifax the outcome would have been different, but it would certainly have strongly increased their chances.

Determination of Pathological Behaviour

The behaviours exhibited by the crew are assessed as typical of denial. This determination is based on the following:

Underlying theme:

A pilot appears to be tactically ignoring information which could be deemed as being of significant threat to their safety.

Specific criteria:

- A threatening stimulus was ignored, or the ramifications of it were ignored, in association with a period of acute stress.
- A serious or critical, and possibly deteriorating situation was unfolding, but inappropriate or no action was taken to address the problem. This was not freezing behaviour, but rather avoidance behaviour.
- The urgency of a developing situation was ignored while under conditions of acute stress.
- The perceived relevance of a stressor was ignored when it was actually relevant.

Event 27a: Loss of Control Inflight Armavia Flight 967, Sochi, Russia

Synopsis

In marginal weather the crew had commenced an instrument approach to Sochi airport in Russia, however ATC advised during the approach that the weather had reduced below minimums. The crew commenced a missed approach but the aircraft became unstable as the captain mismanaged the go-around manoeuvre. A loss of control was followed by GPWS warnings, which were ignored. The crew failed to recover and the aircraft crashed into the Black Sea some four miles off shore.

Having initially pushed the "push to level off" button, and commenced a turn to follow the missed approach instructions, the aircraft bank increased to 25° right roll, at which time the captain then selected a higher altitude on the autopilot control panel. This selection, which was for an altitude above their cleared limit, had the effect of taking the aircraft from a VS mode to an Open Climb mode, which resulted in the aircraft pitching up at 0.3g while still rolling at 25° angle of bank. In this condition the aircraft pitched up to 21° nose up and the airspeed rapidly decreased to 129 knots (eight knots lower than target speed). Shortly after the crew received a "Speed, Speed, Speed" warning, which indicated they were entering a low energy state. The captain's response was to pitch down and to increase thrust to TOGA, followed shortly after by FLX. The pitch down resulted in the maximum flap speed being achieved, prompting him to call for flap retraction, while at the same time, appearing to chase the flaps up "Green Dot"[14] speed by pushing forward on the controls. From this point the captain appears to have become

[14] Green Dot is an electronically generated speed which represents minimum manoeuvring speed without flap

focused on the airspeed only, ignoring the pitch and roll indications on his primary flight display. An EGPWS warning shortly after resulted in the captain pushing forward to 10 or 11° nose down, while continuing to roll the aircraft right. The first officer then intervened, trying to roll the aircraft left, but in so doing increased the pitch down. The aircraft, under the influence of both pilot controls was forced to average the two inputs, resulting in no appreciable change in roll and a slight pitch down. Despite some further inputs by both pilots to roll upright and decrease the pitch angle, the aircraft was not recovered before impacting the water (BEA, 2008).

Analysis

During the go-around manoeuvre the captain, who was somewhat surprised by the requirement for a missed approach, was probably in an elevated state of arousal as the complexity of the situation suddenly ramped up. While in this state it is likely that the captain became startled by a sudden pitch up and roll during the missed approach, conditions which were not managed well. His subsequent control inputs were consistent with a state of confusion and he appears to have attended to only one flight parameter (speed) at the expense of both roll and pitch. The failure of the captain to respond appropriately to the EGPWS warning was also indicative of the confused state which he was in.

Extract from the accident report:

> In spite of the fact that after disengagement of the autopilot the captain recovered the airplane to stable flight with a roll angle of 20° and a small positive vertical speed (about 2 m/s), he probably still felt startled and stressed. Possibly, the captain tried to analyze the cause of such airplane behaviour or his own mistakes. Such a situation could result in mental torpor (stupor). In this state people may be numb and passive or, on the contrary, overactive, when the actions being taken and their expediency become chaotic. In such cases we may talk about the pilot being perplexed. This state can explain inadequate, but still quite active actions by the pilot to increase the airplane roll and decrease the pitch angle, and at the same time his very poor response to the GPWS warning (the PULL UP warning)… During the last 40 seconds of the flight the crew might very well have been in a state of mental torpor (judging by the captain's inputs and taking into account the preceding factors). Being in this state, the crew failed to adequately and comprehensively evaluate the situation and make the right decision. (BEA, 2008, p. 29).

In this accident it appears that the captain had become quite badly startled by an unexpected turn of events (instruction to discontinue approach). This resulted in some automation and handling mismanagement which in turn led to an undesired aircraft state. Two subsequent fear-potentiated startles while in a highly elevated state of arousal are likely to have resulted when the low energy warning sounded and the EGPWS warning sounded. Impaired information processing, which manifested itself in attentional tunnelling and poor decision-making, coupled with poor psychomotor performance and poor crew coordination, are typical of symptoms demonstrated in laboratory experiments following startle. The inappropriate, ineffective and at times inadequate actions which occurred following this series of startles appear to have been instrumental in the loss of control and subsequent accident.

Determination of Pathological Behaviour

The behaviours exhibited by the captain are assessed as typical of startle. This determination is based on the following data.

Underlying theme:
A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.

Specific criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- There were actions consistent with significant confusion, breakdowns in situational awareness, or poor decision-making evident.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 28a: Pilot Induced Loss of Control Inflight Following Wake Turbulence Encounter, New York, Nov 12, 2001.

Synopsis

The A300-600, operating as American Airlines Flight 587**,** took off from John F. Kennedy Airport in New York immediately after a Japan Airlines Boeing 747-400 had departed on the same runway. Shortly after take-off at approximately 1700 feet, the aircraft encountered some wake turbulence from the preceding larger jet's wake. The first officer attempted to keep the aircraft upright with alternating aggressive rudder inputs, however the strength of the airflow against the moving rudder stressed the aircraft's vertical stabiliser and eventually snapped it off entirely, causing the aircraft to lose control and crash (NTSB, 2004).

Analysis

According to the official accident report, after the first officer made his initial rudder pedal input, he made a series of alternating full rudder inputs. This led to increasing sideslip angles. The resulting hazardous sideslip angle led to extremely high aerodynamic loads that resulted in separation of the vertical stabiliser. If the first officer had stopped making these inputs at any time before the vertical stabiliser separation, the natural stability of the airplane would have returned the sideslip angle to near 0° and the accident would have been avoided.
The following extracts from the aircraft accident report describe the events following the wake turbulence encounter:

> At 0915:56.8, (shortly after encountering the wake turbulence) the rudder was deflected 10.2º to the left, and the sideslip angle was about 7º to the left. At 0915:58.4 (the time that the right rear main attachment fitting fractured), the rudder was deflected between 10º and 11º to the right, the sideslip angle was between 11º and 12º to the right. The CVR then recorded, at 0916:00.0, a sound similar to a grunt and, 1 second later, the first officer's statement, "holy [expletive]." At 0916:04.4, the CVR recorded a sound similar to a stall warning repetitive chime, which lasted for 1.9 seconds. At 0916:07.5, the first officer stated, "what the hell are we into … we're stuck in it." At 0916:12.8, the captain stated, "get out of it, get out of it." Following the initial encounter, the control column had moved from approximately 0º (neutral) to 2º nose up, 2º nose down, and back to 0º, while the control wheel moved wheel had moved 64º to the right 78º (full) to the left 2 seconds later, 64º to the right another 2 seconds later, and 78º to the left a further 1 second later. (NTSB, 2004, p. 5).

Following the initial wake turbulence encounter it appears that the first officer became surprised by the rapid roll rate and subsequently made some extreme and excessive control inputs in the roll and yaw axes. His exaggerated control movements were indicative of the psychomotor impairment observed following startle in several laboratory experiments (e.g., Touchstone & Thackray, 1970).

It is likely that the first officer, who may not have been expecting the wake turbulence, or at least the severity of it, suffered a strong startle, indicative by the expletive issued shortly after the encounter. The gross control inputs were outside normal recovery requirements and were probably the result of impaired information processing and psychomotor performance following the startle.

Determination of Pathological Behaviour

The behaviours exhibited by the first officer are assessed as typical of startle. This determination is based on the following information.
Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.
Specific Criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.
- Psychomotor skills were significantly degraded from normal performance levels, or impairment was apparent, for some time following a surprising stimulus.
- Communication following the surprising stimulus was broken, haphazard, or incoherent, for a significant period of time.

Event 29a: Stalled After Takeoff Due to Airframe Icing, Tyumen, Russia, 2 April, 2012

Synopsis

Following an extended layover on the ground, the aircraft had accumulated a substantial amount of airframe icing. For an unknown reason the captain, in consultation with an engineer, elected not to de-ice the aircraft prior to departure. During the taxy out the aircraft once again encountered icing conditions, which may have contributed to a further ice build-up on the wings.

After takeoff the aircraft climbed to an altitude of approximately 600 feet where flap retraction was initiated. As the flaps became fully retracted at a speed of 150 knots, the aircraft immediately entered a stall, which was precipitated by the aircraft rolling right to 40° bank in three seconds. The autopilot was disconnected and a correction was made by the PF to counter the roll, however the aircraft then rolled sharply left and descended in to the ground.

Of the 43 people on board, 33 were killed and ten were seriously injured.

Analysis

According to the official accident report, the flap retraction was initiated at 640 feet at a speed of 139 knots. Under icing conditions the reference speed for flap retraction should have been 160 knots.

At the end of flap retraction the aircraft commenced a self-induced bank due to the onset of stall. While the crew had noted some buffeting, there were no stall warnings provided by the aircraft's systems.

The crew did not take any action to correct the stall following buffet, activation of the stick shaker, or activation of the stick pusher. While the correct control inputs would have been to lower the nose to reduce the angle of attack, the control column movement was rearward, indicating that the crew were pulling back, in opposition to the stick pusher. This would likely have done nothing to aid in recovery and would likely have exacerbated the stall condition.

According to the official accident report, the immediate cause of the accident was the captain's decision to take off without de/anti-icing treatment, despite the fact that snow and ice deposits were observed by the crew during taxy. These deposits resulted in degradation of aircraft aerodynamic performance and a stall during climb out after take off. The crew failed to recognise the stall and consequently failed to undertake an appropriate recovery procedure.

Determination of Pathological Behaviour

The behaviours exhibited by the PF are assessed as typical of startle. This determination is based on the following information.

Underlying theme:

A pilot suddenly encountered an unexpected and/or surprising stimulus, which induced cognitive and physical effects which momentarily, or for some time following the stimulus, resulted in ineffective, inappropriate, or inaction type behaviours.
Specific Criteria:

- An unexpected and/or surprising stimulus in the aural, visual and somatic modalities was experienced, which was of sufficient valence to be rapidly noticed.
- A surprising stimulus was followed by a response which was either inappropriate, ineffective, or in contravention of rules, SOPs, or training expectations.

Appendix B Startle Exercise Candidate Data Form

The following form incorporates demographic data which was used to make quantitative analysis of the startle reactions observed during the simulator exercises. The form was completed immediately prior to briefing the simulator exercise, approximately 15 minutes before the exercise was commenced.

Limitations

No data was collected for gender or for currency. Analysis of performance based on gender may have indicated some interesting performance effects in a large sample, however, given the number of participants involved, there was insufficient data to be of significance.

Some data could have been gathered regarding currency of the pilots involved. While all were currently line pilots with various airlines, determining how long since they had last flown may have contextualised the results further. This was not considered at the time but would be considered for future experiments.

Startle Research

Date____________________________

Candidate No. [ ]

Position: Captain / First Officer

Age: [ ]

Total Flying hours: [ ]

Total hours B737: [ ]

Appendix C Startle Exercise Debrief Form

The following form was completed during a debrief with each subject immediately following completion of the second instrument approach in the flight simulator. The debrief took part in the same briefing room where the exercise was briefed prior to the simulator exercises and was recorded on digital audio tape for review, in the event that further clarification was required. This audio material was not required during analysis due to the clarity and simplicity of the data obtained.

Limitations

The whole flying exercise took from 30-40 minutes depending on the set up and reset time taken by each subject. Some were happy to get underway with minimal preparation, while others felt more comfortable completing taxi and before takeoff checklists, as they would for a normal flight. Neither of these preparatory extremes likely had an effect on the exercise as the startle did not occur for approximately 15 minutes after first getting airborne.

The delay in debriefing the subjects on their physiological and cognitive perceptions of startle after the first approach allowed some 15-20 minutes between the startle event and recollection of the event. Given the enduring nature of emotional memory and the relatively short time involved (15-20 minutes), this delay was considered preferable to debriefing the startle exercise immediately following the first approach. Doing so may have introduced other variables into the validity of the second approach which was subsequently used as a baseline for comparing the first approach results.

Date___________________________

Candidate No.

Debrief Items

1. On a scale of 1-10 how much of a startle did you receive, with 1 being virtually nothing and 10 being a major fright.

2. Did you experience any physiological signs of startle such as increased heart rate or respiration?

HR

RESP

OTHER

____

3. Did you experience any momentary confusion, inability to process information, or difficulty in remembering procedures after the startle?

4. If so for approximately how long did this last?

5. Research travel expense payment.