Eliminating CFIT and loss of control from commercial air operations: the problems and the solutions

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When flying in instrument meteorological conditions (IMC) - conditions where all visual reference to the earth's surface and horizon is removed – pilots are taught to construct a 3D mental model of the attitudinal position of the aircraft in 3D space, including their current position along the intended flight path, using information and data which has been extracted from the flight instruments and factored to include any additional operational parameters. Theoretically, it is a straightforward process, and the flight instruments are specifically designed to enable safe, effective control of the aircraft in IMC. Yet, how often following a serious aviation accident do media reports state 'Weather conditions at the time were reported as poor'? As accident records confirm, 98% of all fatal CFIT and LoC accidents involving commercial aircraft operations occur whilst the crew are flying on instruments in IMC (source: BAAA, 2015). But how can professional pilots lose control of a fully functional aircraft in IMC; or CFIT an aircraft in IMC, whilst flying on the instruments which were specifically designed to enable safe flight in IMC? This paper proposes that there are five distinct, but intrinsically linked issues, which, when events conspire, align to enable a LoC or CFIT trajectory to progress unchallenged, to a fatal outcome.

1. Introduction

This year, as in every year since accident records began, hundreds of people will be killed because of two specific groups of aviation accidents – accidents which, despite other advances in aerospace safety, continue to elude eradication. They are: (1) controlled flight into terrain (CFIT) – flying a perfectly serviceable and fully functioning aircraft into the side of a hill or a mountain, or into the ground some distance short of the runway on approach to land; and (2) loss of control (LoC) – putting an aircraft into an irrecoverable and fatal situation, where it literally falls from the sky. The cost in human life is staggering. In the first fifteen years of the 21st century (2000–2014), 15,835 people met violent deaths in 2,339 commercially operated aircraft accidents (source: BAAA, 2015). On average, that is thirteen fatal commercial aircraft crashes per month (and these figures do not include the two instances of suspected pilot suicide; or the two Malaysian Airlines' flights (MH017 which was shot down, and MH370 which went missing); or any military or private flight accidents). These figures solely relate to accidents in the commercial flight sector resulting from known or suspected CFIT or LoC.

At the subsequent enquiry following a CFIT or LoC, 'pilot error' is most often cited as the probable cause. Whilst that finding may be factually correct, in that the pilot did make an error resulting in the complete loss of the aircraft, such enquiries often fail to fully answer two questions: 'Why did the pilot make the error?' and 'What caused the situation to escalate into an irrecoverable CFIT or LoC?' Clearly there is a problem, because CFIT and LoC together – and it is often impossible to separate them – continue to exact an unacceptable annual toll in human life, and cost the global insurance industry millions of dollars each year. So how could a medically fit, fully licenced professional pilot, in current flying practice, fly into a hill or a mountain, or into the ground some distance short of the runway on approach to land; or lose control of a fully serviceable aircraft so that it literally falls from the sky?

2. The problems

2.1 Display motion relationships: the horizon reference

The principal visual component for control of the aircraft in IMC is the attitude indicator. This consists of two main elements: a representation of the aircraft and a representation of the horizon. The first form of this instrument, the artificial horizon, was designed for a 1929 blind flying experiment under the direction of John Poppen, who was not a pilot. The instrument uses a moveable metal disc with a line inscribed across the centre – as the equator would be depicted on a flat picture of the earth. That line represents the earth's horizon as seen whilst flying. By the use of a gimbal arrangement, the moveable artificial horizon line remains aligned to the earth's real horizon throughout the flight. A fixed reference representing the aircraft (as viewed from behind, and in the direction of flight), is placed over the horizon line, and in the centre of the instrument. When flying level, the fixed aircraft reference and the moveable horizon reference align - one over the other. When the aircraft is climbing, descending, or turning, the angle of displacement between the aircraft and the horizon is represented on the instrument. According to Roscoe (1999), Poppen, who was a naval surgeon, envisaged the instrument as replicating the view of the horizon as seen through a porthole of a ship. As the ship moves in a swell, the horizon can be seen to pitch and roll through a porthole. As a replication of that view, Poppen's artificial horizon is absolutely accurate, and that basic form of depicting the relative positions of the horizon and aircraft has remained constant in all attitude indicators, including electronic 'glass cockpit' displays.

There are, however, two fundamental inherent issues with this form of representation, which were originally observed by James Doolittle (the first pilot to successfully fly using an artificial horizon): (a) Poppen's concept is based on a visual illusion. It is not the horizon which is pitching and rolling, it is the ship. The horizon is a fixed static reference and not a dynamic reference. (b) The representation is not intuitive; the moving element of the instrument – the horizon – is rolling in the opposite direction to the roll of the ship, or the aircraft; if the aircraft rolls left, the horizon rolls right. Roscoe (1983; 1986; 1997; 1999), who conducted numerous experiments and wrote extensively about the causes of LoC, considered the moving horizon to be the core issue in control reversal leading to LoC. It is certainly known that in a number of LoC accidents, pilots, when attempting to correct an uncommanded unusual attitude / position involving roll, have applied correction in the wrong direction (control reversal) – by attempting to 'fly' the moveable horizon, and escalated the error; ultimately becoming disorientated (Roscoe, 1983; 1997). However, even though some Soviet manufactured instruments do employ a moveable aircraft reference and fixed horizon (which addresses Roscoe's concern), CFIT and LoC remain an issue in eastern Europe.

2.2 Swiss Cheese Model: the missing element

One accepted model of human factors causation in CFIT accidents is Reason's *Swiss Cheese Model* (1990), which considers latent and active causal elements. Lack or failure of intervention is represented by holes in the slices of cheese, allowing an accident trajectory to progress. Reason's (and others') work has been widely adopted in aviation because it describes complex systems which require human operators; which have layers of organizational structure; and well established industry cultures, practices, norms and procedures. But irrespective of the merits, and there are merits, there is one fundamental aspect of Reason's model which does not fit with aviation. The *Swiss Cheese Model* was originally created to describe human factors accidents in large industrial installations. Despite all other factors, the operators of a power station or oil

refinery are in an environment which is fixed, static, and firmly bolted to the ground – it does not move. A static, non-moving environment is a normal and natural environment for a human being to work in. Conversely, in extreme tropical thunderstorms, severe turbulence, or torrential monsoon rain, the working environment of an aircraft pilot can be moving violently in three dimensions. That is an environment which, evolutionarily, is abnormal for a human being to work in. And when the flight-deck of an aircraft moves suddenly, violently, in any of the three axes of flight movement due to adverse meteorological conditions whilst in IMC, it can become, in effect, the world's most extreme and terrifying roller-coaster ride – and one where the fear is real.

2.3 The vertical polarity reference

One of the ways in which humans maintain balance, is to subconsciously relate dynamic physical movement, against fixed references such as the verticals and horizontals in the environment and in buildings (which is why buildings generally have straight walls and ceilings). That is also how we assess such things as the steepness of a hill. Information from the eyes is cross referenced within the brain against information arriving from the inner-ear vestibular motion-sensing canals, and other sensors in our joints, to confirm polarity. When there is confusion such as disturbance in the inner-ear canals, the eyes will attempt to lock onto fixed vertical and horizontal references to restore vertical alignment. But on an artificial horizon, the 'fixed' reference which can confirm static alignment, is the element of the instrument which is in motion – and it may be displaying an unusual or extreme position.

2.4 Constructing the mental model

Consider the sources of information which a pilot requires to construct a mental 3D model of the aircraft's current and projected positions. The first and primary source of information is the attitude indicator, which is a semiotic representation of the aircraft relative to the horizon as viewed from behind the aircraft looking forward. Next, is the airspeed indicator, positioned by convention to the left of the attitude indicator. In electronic instrument forms, this is a tape depicting numeric values, which moves vertically up and down to indicate the current airspeed in a window. At various positions along the tape, coloured edge-bands indicate critical speed limits: for extending wingflaps, leading-edge lift devices, and the undercarriage; maximum turbulent air speed, and never exceed speed. Positioned by convention to the right of the attitude indicator, is the altimeter. This too is a numeric tape with the current value displayed in a window. Alongside this is normally displayed a rate of climb or trend indicator, which may portray values as a digital representation of an analogue needle. Various other values such as altimeter pressure settings are displayed around the screen in various positions.

Beneath the attitude indicator, the radio navigation display is positioned. This screen can present various information pages. Normally, this includes a skeletal navigation route, as viewed from overhead looking down, termed 'God's eye view' (GEV), with VOR and NDB navigation beacon idents; reporting points; and GNSS (GPS) waypoints positioned along it. Also displayable is a combined VOR/ADF RMI navigation indicator and direction indicator. The VOR indicator is a hybrid – part forward looking semiotic, part overhead GEV – which rotates on screen to point relatively to the radio signal sources selected. The VOR is also used for the ILS, although the values are different in the two modes. When combined with a direction indicator, the VOR/ADF indicator is called an horizontal situation indicator (HSI).

So to construct and update the basic 3D mental model, the pilot extracts seven pieces of information (attitude; airspeed; altitude; vertical speed; slant range (DME); magnetic heading and radio navigation direction (HSI); in five different information forms

(semiotic; overhead GEV; hybrid (GEV, and through the aircraft); numeric data; analogue trend); in three different views (semiotic through the aircraft; hybrid; and GEV); and then applies a numeric factor to some of this information to comply with company standard operational procedures.

2.5 Human evolution; environment – and the consequences for piloting aircraft There is still some uncertainty about when exactly humans developed in Africa, and why they migrated to populate other areas of the earth. What is known is that hominins, including Homo sapiens, human beings, evolved to live in an environment which is static. The human is the moving element in a static environment. They also evolved in an environment where the only law was 'survival of the fittest' - kill, or be killed; eat, or be eaten. Our early ancestors' lives were brief - and dangerous. In order to survive in this hostile, predatory environment, where a fight to the death could be a daily occurrence, humans evolved a defence mechanism which Cannon (1932) described as 'the fight-or-flight response' - and which every human alive today still possesses. (Had our ancestors' defences been weak or defective, they would not have survived to pass on their genetic code to us. Only the fittest survived.) So when confronted with a sudden threat, the 'fight-or-flight response' provided an edge in survival. It achieves this by modifying the body's responses and reactions to the threat, and augmenting physical performance through the almost instantaneous secretion of catecholamine hormones – a complex group of natural chemicals which include adrenaline – into the bloodstream. The effect is immediate as the body prepares to fight, or run away. All of the systems the body needs to fight to the death or run for its life are now powered-up to the absolute maximum, and are ready for the conflict.

Simultaneously, systems which are not required for the fight, or flight, are shut down. One consequence of this is that cognitive capability significantly diminishes. As blood is moved from the brain to the muscles, the ability to think, to process information and to analyse data begins to close down, and in many instances can completely cease. There is, however, a second and even more problematic issue with the 'fight-or-flight' response. According to Weekes (1978) (whose work focused extensively on nervous conditions such as agoraphobia, claustrophobia, and panic attacks), the consequences of continuing catecholamine secretion arousal in a 'trapped' environment [such as a cockpit] is the rapid progression to fear paralysis. A person can quickly become so supertensed with overwhelming feelings of impending disaster that they become immobilized, rigid, and unable to move: a situation often described in phrases such as 'scared stiff'; 'petrified'; 'frozen rigid'. And the five stage progression of escalation to paralysis is extremely rapid: from (1) initial flash of sensitisation, to (2) confusion, to (3) blind-reflex / instinctive action, to (4) complete bewilderment, and finally (5) fear paralysis (Weekes, 1978).

When flying on instruments in adverse or extreme IMC, what evolved as an essential defence mechanism for our primitive ancestors, now becomes a serious liability for the pilot. If catecholamine hormone floods into the bloodstream, the cognitive capability to extract and factor five forms of numeric / alpha-numeric data, semiotic, and hybrid representations, then construct a 3D mental model of the current and emerging situation, rapidly diminishes – and in high levels of catecholamine 'fight-or-flight' response arousal, may completely cease.

That is the exact point at which the pilot's subsequent actions may result in a verdict of 'pilot error' (Wilson, 2007). If, due to severe weather and turbulence initiating catecholamine hormone secretion (stage 1), a pilot cannot make sense of the information presented on an approach to land (stage 2), their instinctive actions (stage 3), may lead to CFIT. If, following confusion (stage 2), the pilot with instinctive action (stage 3), tries to fly the moving element of the artificial horizon level, and escalates the problem, bewilderment (stage 4), and loss of control may quickly follow. In many LoC

investigations (Roscoe, 1997), the control column, on impact, has been discovered being held in full deflection – in the wrong direction (stage 5).

3. Discussion

The objective is not to take the pilot out of the process of flight; the objective is to take pilot error out of the process of flight. *All* pilots are subject to 'fight-or-flight' catecholamine hormone performance degradation. But aircraft, sensors, and systems are not. Technologies do not get frightened, tired, hungry, or emotionally upset. Fact: In every CFIT and LoC, the aircraft actually knows where it is, and the proximity of the fatal outcome – but is unable to do anything about it. The aircraft knows that a mountain slope is in the direct track being followed; it knows the current airspeed is diminishing rapidly towards a stall, for which there is insufficient altitude to recover. It knows exactly where the ILS localiser beam is and the correct angle and power settings required to intercept, and fly the approach.

4. The solutions

To eliminate pilot error, this paper proposes a clear division of roles and tasks, with the aircraft becoming a fully co-participating partner in the process of flight – with an interest (albeit artificial) in its own survival and the safe outcome of the flight. The process of flight is narrative based, with a straightforward sequential progression of phases – even in emergency scenarios and diversions (Wilson, 2004; 2007; 2009). Each phase of the flight has specific tasks and events. So in the division of roles, the aircraft handles all phase-pertinent information abstraction, data manipulation, calculations, factoring, and presentation – using a totally separate, augmented-intelligence, independent overview system with IPRS algorithms, an embedded IoT network, EFB, and external datalinks. Via the vehicle-wide application of cyber-physical systems, the IPRS monitors vehicle health, and collates, factors, and presents all of the information for each phase of flight, including events such as the departure briefing, and top-ofdescent pre-approach briefing. It provides the pilots with clear, straightforward, unambiguous truth, verbally through plain language voice prompts, information, and cautions, and visually via a phase-pertinent, narrative based, fully congruent, visually integrated, single wide-screen VIVID presentation of the current situation and projected trajectory – and in a manner which (a) does not require any interpretation, factoring, translation or cognitive manipulation; (b) which cannot be misread, misinterpreted, or misunderstood; and (c) which enables full situational awareness, control authority, and pilot confidence to be maintained, even in the most adverse meteorological extremes (Wilson, 2004; 2007; 2009).

Abbreviations (not otherwise explained in text)

- ADF Automatic Direction Finder
- DME Distance Measuring Equipment
- EFB Electronic Flight Bag
- GNSS Global Navigation Satellite System
- GPS Global Positioning System
- ILS Instrument Landing System
- IoT Internet of Things
- IPRS Intuitive; Predictive; Reactive; Selective
- NDB Non-directional Beacon
- RMI Radio Magnetic Indicator
- VHF Very High Frequency
- VIVID Visually Integrated Variable Intensity Display

VOR VHF Omni-directional Range

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