Introduction

Human error is often cited as a major contributing factor or cause of incidents and accidents. Incident surveys in aviation have attributed 70 per cent of incidents to crew error, citing pilot error as the root cause of an aviation accident (Woods et al., 1994). This limited view of accident causation reflects a fundamental misunderstanding of the aetiology of aviation accidents. The anatomy of disasters and accidents in complex technological systems, such as aviation, show an aetiology that is reflected in the latent failure model of complex systems (Woods et al., 1994). The case studies discussed in Bennett (2001), illustrate the complex and convoluted aetiology of aviation accidents and thereby support the requirement for a holistic or systemic view of disasters as proposed by Reason and Norman (Bennett, 2001). Building on the foundation of human error as proposed by Reason, a model is described that helps illustrate the nature of aviation accidents. This model is based on catastrophe theory as proposed by Thom (Woodcock and Davis, 1978). The mathematical complexity of catastrophe theory is presented in a descriptive schema such that the rich geometrical features of the model can be used in an illustrative manner. The cusp model is used as a descriptive and predictive illustration of the dynamics of situational factors and latent conditions to help explain the nature of aviation accidents based on Reason’s latent failure model.

Holistic approach to human error

Although a large proportion of the accidents can be attributed to human error, Reason proposes a view that many accidents are catalyzed by persons not present at the time of the event (Bennett, 2001). Characterized as a safe mode of transportation, the hazards associated with aviation are mitigated through the advent of barriers and safeguards. However, these barriers can be breached/eroded through human, technical and organizational factors thereby precipitating a catastrophic event. Since people design, manufacture, operate, maintain
and manage complex technological systems, human decisions and actions are implicated in all organizational accidents (Reason, 1998).

The complex nature associated with the aetiology of aviation accidents supports the requirement for a systemic approach to accident causation. Viewing errors as consequences rather than causes, Reason identifies two types of errors: active errors and latent conditions. Active errors are unsafe acts committed by people who are in direct contact with the system. These active errors include slips, lapses, fumbles, mistakes and procedural violations. Usually these active failures are characterized as being immediate and relatively short-lived (Reason, 1998) whereas latent conditions can lie dormant for a time, doing no particular harm until they interact with local circumstances to defect system defences. Latent conditions are always present in complex systems and are seeded into the system since they are the inevitable product of strategic decisions (Reason, 1998).

Latent failures include:
- poor design;
- gaps in supervision;
- undetected defects;
- unworkable procedures;
- clumsy automation;
- short fall in training; and
- less than adequate tools.

They arise from the strategic and other top-level decisions made by governments, regulators, manufacturers, designers, organizational managers. The impact of these decisions spreads throughout the organization, shaping a distinctive corporate culture and creating error-producing factors (Reason, 1998).

Within the situational dimension, the active failures and associated situational conditions share a common axis. These situational factors may act as a trigger enabling the latent conditions, thereby activating a series of effects or consequences resulting in a possible disastrous outcome.

In addition, the insidious nature of latent conditions can increase the likelihood of active failures through the creation of local factors promoting errors and violations.

Latent factors and system defences

The systems approach to human error contains safeguards and defences in a layered schema in order to mitigate the danger to potential victims from local hazards. Reason’s latent failure model conceptualizes the defensive layers within the system. The holes represent the active and latent conditions present in the system. The alignment of the holes permits a trajectory of accident opportunity. A characteristic of such defences is that they do not always respond to individual failures. As articulated by Reason, the failure can be either countered or concealed and in neither case need the individual directly concerned be aware of their existence. This can facilitate the build-up of latent conditions or “resident pathogens” that may subsequently combine with local conditions and sharp end errors to breach or bypass the defensive layers, precipitating into an accident or disaster (Reason, 1998).

Catastrophe model

Catastrophe theory provides a unique perspective in the way we look at change, whether it be a change in a course of events, an objects shape, or a systems behaviour. It is particularly suited for an event that is characterized by an abrupt change or a discontinuous transition. It facilitates the prediction of the shapes of processes, where its descriptions and predictions are not quantitative but work rather as maps without scale (Woodcock and Davis, 1978). For a detailed description regarding the mathematical complexity of catastrophe theory and the cusp model, the reader is referred to Poston and Stewart (1978). In this discussion of aviation accident aetiology, the application of catastrophe theory is limited to the rich geometrical descriptive features of the cusp model. A mathematical catastrophe is a point in a model of an input-output system where a small change in the input can produce a large change in the output. The structural features represented in the graphical presentation illustrate the nature of the event under analysis and incorporate information about the causes
and effects. The “catastrophe” itself can be thought of as a jump from one state or pathway to another. The underlying characteristic of this catastrophe is that the transition from the initial state or pathway to another is brief in comparison to the time spent in the “stable state”. The applications of catastrophe theory can be seen in such fields as natural science, sociology, economics, politics, and psychology, to name but a few.

We can conceptualize a catastrophe by viewing a system consisting of a ball free to roll under gravity in a double-well container that can be tilted from one side to the other. Here the input is the tilt of the container, and the output is the position of the ball. Figure 1 illustrates this one-dimensional model.

We can illustrate the catastrophe graphically by representing stable states as sets of points, lines or surfaces in a “behaviour state”. The cusp catastrophe, Figure 2, is a representation of a behaviour that depends on two control factors. Presented as a 3-D curved surface with a pleat, the equilibrium states within this graph are characterized as points on the surface. The underside of the pleat represents unstable maxima whereas the lip of the pleat represents semi-stable points of inflection. The bimodal behaviour of the system is subject to changing conditions with time. The green and blue regions represent stable potential wells, whereas the shaded region represents the unstable inaccessible region. The smooth transition of a point on the surface with respect to changing control factors is abruptly interrupted by the possibility of a discontinuous change that occurs when a point reaches the lip of the pleat. A change in control factor 1 or 2 may result in the transition of the point across the pleat. This transition is a catastrophe.

Mapping aviation accidents aetiology

The dynamic nature of aviation and associated risks is a function of the situational factors and latent conditions present at the time. Both share a temporal and spatial element. Reason’s latent failure model is mapped onto the 3-D space of the cusp model (Figure 2), in order to illustrate the instability created when active errors (control factor 1) and latent conditions (control factor 2) combine to place the point at the pleat, thereby leading to a catastrophic event. In this model, the active errors are contained as features within the situational factors. Mistakes

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**Figure 1 One-dimensional catastrophe model**

1. 2. 3. 4. 5. 6. 7. 8. 9.

**Position of Ball**

Left ........ Right

3. 60
4. 30
5. 0
6. -30
7. -60
8. 

**Key**

- Green
- Blue

**Note:** There is one catastrophe just beyond the configuration labelled 2 in the figure and on the graph. This is the point where the ball is just poised to fall to the left, but is still balanced on the right side of the well. If the ball is exactly at that point, the tiniest additional tilt will cause a large displacement of the ball (green arrow). A symmetrical catastrophe is just beyond the configuration labelled 6. The catastrophe in this system is a one-parameter, or “co-dimension 1” catastrophe: there is one controlling variable, namely the tilt of the well. Other mathematical catastrophes share an important feature of this system: the output is determined by a mechanism (in this case, gravity acting on the ball) that seeks the lowest possible position compatible with the constraint (in this case, staying in the well).

**Source:** www.ams.org

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or errors within the catastrophe model will result in a move toward a more negative situational factor. These active errors may act as a trigger enabling the latent factors, thereby activating a series of effects or consequences with possible disastrous outcomes. The latent conditions are contained within systemic factors and range in value from low to high based on their emergence during a flight safety event.

Point A represents a scenario characterized by positive situational factors and low systemic factors where the potential for a flight safety incident is very low. As the situation deteriorates the scenario develops a dynamic nature characterized as a movement along the axis. This situational factor triggers the latent (systemic) conditions characterized as a movement from point A to point B in Figure 3. If uncorrected, a catastrophic event may occur beginning with the movement from point B to C where the instability of the situation results in the catastrophic event characterized by the movement from C to D. Similarly, situational factors may continue for sometime before triggering the latent conditions, as characterized as the movement from A to C.

The complexity of the disaster aetiology stems from both the scale and coupling of the systems (not only the physical aircraft systems but also the organizational systems that support the operation). This complexity creates a pattern of disaster that evolves or is precipitated through a series of several small failures. The cusp model facilitates the mapping of Reason’s latent failure model, providing a descriptive and predictive illustration of the emergence of latent conditions under the trigger of situational factors. The risk of an accident increases as the situational and systemic factors combine to create an inherent instability resulting in the catastrophic event.

**Case study**

On 2 September 1998, SwissAir Flight 111 departed New York, USA, at 20.18 eastern daylight savings time on a scheduled flight to Geneva, Switzerland, with 215 passengers and 14 crew members on board. About 53 minutes after departure, while cruising at flight level 330, the flight crew smelled an abnormal odour in the cockpit. Their attention was then drawn to an unspecified area behind and above them and they began to investigate the source. Whatever they saw initially was shortly thereafter no longer perceived to be visible. They agreed that the origin of the anomaly was the air conditioning system. When they assessed that what they had seen or were now seeing was definitely smoke, they decided to divert. They initially began a turn toward Boston; however, when air traffic services mentioned Halifax, Nova Scotia, as an alternative airport, they changed the destination to the Halifax International Airport. While the flight crew were preparing for the landing in Halifax, they were unaware that a fire was spreading above the ceiling in the front area of the aircraft. About 13 minutes after the abnormal odour was detected, the aircraft’s flight data recorder began to record a rapid succession of aircraft
systems-related failures. The flight crew declared an emergency and indicated a need to land immediately. About one minute later, radio communications and secondary radar contact with the aircraft were lost, and the flight recorders stopped functioning. About five and one-half minutes later, the aircraft crashed into the ocean about five nautical miles southwest of Peggy’s Cove, Nova Scotia, Canada. The aircraft was destroyed and there were no survivors (www.bst.gc.ca/en/reports/air/1998/a98h0003/a98h0003.asp).

The findings from the final report (www.bst.gc.ca/en/reports/air/1998/a98h0003/a98h0003.asp) show an accident aetiology that reflects Reason’s latent failure model. Situational factors such as the loss of primary flight displays and lack of visual references forced the pilots to be reliant on the standby instruments for at least some portion of the last minutes of the flight. In the deteriorating cockpit environment, the positioning and small size of the instruments would have made it difficult for the pilots to transition to their use, and to continue to maintain the proper spatial orientation of the aircraft (www.bst.gc.ca/en/reports/air/1998/a98h0003/a98h0003.asp).

Unable to recover, SwissAir 111 suffered a catastrophic event culminating in the loss of 229 lives. Latent (systemic) factors that can be construed to be a contributing factor include the following (www.bst.gc.ca/en/reports/air/1998/a98h0003/a98h0003.asp):

- Aircraft certification standards for material flammability were inadequate in that they allowed the use of materials that could be ignited and sustain or propagate fire.

- Metallized polyethylene terephthalate (MPET) type cover material on the thermal acoustic insulation blankets used in the aircraft was flammable . . . and contributed to the propagation and intensity of the fire.

- The type of circuit breakers (CB) used in the aircraft were similar to those in general aircraft use, and were not capable of protecting against all types of wiring arcing events.

- There were no built-in smoke and fire detection and suppression devices in the area where the fire started and propagated, nor were they required by regulation. The lack of such devices delayed the identification of the existence of the fire, and allowed the fire to propagate unchecked until it became uncontrollable.

- There was reliance on sight and smell to detect and differentiate between odour and smoke from different potential sources. This reliance resulted in the misidentification of the initial odour and smoke as originating from an air conditioning source.

- The loss of primary flight displays and lack of outside visual references forced the pilots to be reliant on the standby instruments for at least some portion of the last minutes of the flight. In the deteriorating cockpit environment, the positioning and small size of these instruments would have made it difficult for the pilots to transition to their use, and to continue to maintain the proper spatial orientation of the aircraft.

The findings and conclusions detailed in the final report (www.bst.gc.ca/en/reports/air/1998/a98h0003/01report/03conclusions/rep3_01_00.asp) show an accident aetiology with many contributing factors. The descriptive and predictive nature of the cusp model as shown in Figure 3 facilitates a unique approach to the examination of the SwissAir accident whereby overlaying the latent (systemic) conditions coupled with the situational factors illustrates how the alignment of the latent conditions can create a condition of instability to the point where a catastrophic event occurs.

**Conclusion**

The anatomy of disasters and accidents in complex technological systems, such as aviation, show an aetiology that is reflected in the latent failure model of complex systems (Woods et al., 1994). Building on the foundation of human error as proposed by Reason, a model is described that helps explain the nature of aviation accidents (Reason, 1990). Situational factors and systemic factors (latent conditions) are mapped onto the
cusp catastrophic model to facilitate a
descriptive and predictive illustration of
the dynamics of situational factors and
latent conditions to help explain the nature
of aviation accidents. This model, by way
of its features, illustrates the trigger effect
of active failures (captured within the
situational factors) and how it precipitates
the systemic conditions, resulting in a
disastrous outcome. The tragic SwissAir
111 crash is used as an example of how
the control factors of the cusp model
combine to create a situation whereby
instability ensues and a catastrophic
event occurs.

References

Bennett, S. (2001), Human Error – by Design?, Perpetuity
Press, Leicester.

Poston, T. and Stewart, I. (1978), Catastrophe Theory and Its
Applications, Pitman, London.

Reason, J. (1990), Human Error, Cambridge University Press,
Cambridge.

Reason, J. (1998), Managing the Risks of Organizational
Accidents, Ashgate, Aldershot.

Woodcock, A. and Davis, M. (1978), Catastrophe Theory,

Behind Human Error: Cognitive Systems, Computers,
and Hindsight, Crew Systems Ergonomics Information
Analysis Center (CSERIAC), Wright-Patterson Air Force
Base, Dayton, OH, December.