THE HIDDEN DANGERS OF RUNWAY EXCURSIONS

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ABSTRACT

Overrun accidents continue to occur despite the good intentions of those involved in identifying and managing risk. Our ability to predict and prevent accidents that “can’t happen” must depend on our willingness to look for the possibilities in what our conventional ways of seeing assure us are failure-proof systems. In 1968 astronaut Frank Borman said it was a “failure of imagination” that led to the Apollo I fire. Today, as economic pressures work to squeeze more capability from our airplanes, pilots, and runways, the question remains not “could a runway excursion occur” but “will it be our inability to imagine risk that contributes to the next runway accident”? This paper will focus on the different ways risk can be measured as well as how the nature of randomness can influence our perceptions of safety. By examining the interrelated effects of probability modeling, safety assurance practices and current policies and regulations a new definition of safety hazards and mitigations will be defined.

Keywords: Uncertainty, Black Swan, safety management systems, safety assurance, naval aviation.

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1. INTRODUCTION

The professional aviation community stands on the firm conviction that we live in a world where knowledge has the absolute power to vanquish uncertainty. According to Gittens (2011) "ICAO statistics indicate (that) runway excursions are both the most frequent and most deadly type of runway incidents that can occur." To this end, various organizations have endeavored to identify and classify the components that lead up to such an event. Our world is knowable to most people, and therefore our exposure to risk is also knowable. What we don't know today we can almost certainly know it tomorrow. We think this way because it is the way an engineer thinks, and if there's one thing our aviation world is built upon, it's the certainty and predictability that the engineering approach to building and operating machines provides us. But what if our world wasn't as predictable and certain as we thought it was? What if uncertainty itself was the product of our design process? Could that change the way we identify hazards and manage risk?

2. UNCERTAINTY

What you don't know can be more important than what you do. Risk is the relationship between the probability that something will happen and the resulting consequences if it does. In order to understand the risk inherent in an action, we must take a closer look at the properties of probability itself and understand the difference between randomness and predictability. To frame the discussion of runway safety in this context we will look at how randomness was first introduced in classical scientific reasoning, how it was used to influence decision-making models, and how randomness can affect probability in very different ways. We will then look at how risk is managed in carrier landings at sea and compare that to the safety management/safety assurance methods available to the civilian community. We will conclude by looking at how the limits of our knowledge affect our view of runway overrun risk and the possible remedies available to us.

"God does not play dice with the universe" was the famous quote from Einstein. For him the universe operated according to a grand design, with nothing left to chance. His Theory of Relativity was the ultimate triumph of reason over chaos. And so it annoyed him to no end when a young physicist named Werner Heisenberg, and the respected Niels Bohr, developed a theory of quantum physics that spelled out precisely the opposite. The problem started innocently enough when a Scottish botanist was examining pollen suspended in water under a microscope back in 1827. Unlike Einstein's universe, Brownian motion was chaotic and patently unpredictable. As Werner Heisenberg searched to understand why the atoms in water behaved in such a way he stumbled upon a branch of mathematics called matrix algebra that seemed to solve this problem quite elegantly. Forget trying to understand why atoms behaved the way they did, what was critical was the probability of their behavior. In the strange and bizarre world of the quantum particle, something could exist and not exist at the same moment, for no rational reason whatsoever! The uncertainty about its existence would forever remain a scientific constant (Lindley, 2008). Uncertainty lingered in the cloud chambers, spectrographs, and Geiger counters for everyone to see; sometimes things simply did "just happen," and for reasons that would forever remain a mystery.

The most dramatic illustration of this concept in the aviation world came from the work of a junior Air Force pilot named John Boyd who looked at the performance of the F-86 Sabre during the Korean War and came up with a groundbreaking discovery. Boyd was familiar with Heisenberg's work, but it was the random movements of an enemy fighter that concerned him. When compared to the MiG 17, the enemy's aircraft, the F-86 was inferior on paper in more than a few aerodynamic aspects. What made the F-86 such a formidable fighter, however, was how it was built on Heisenberg's observations regarding uncertainty. The cockpit layout, the size and position of the canopy, and especially the hydraulically boosted controls— all features of the MiG in which it was deficient—enabled the Sabre pilot to use uncertainty as a weapon by allowing him to modify his actions much quicker than his opponent. The theater of aerial combat was in many ways like the inner workings of the atom. Empirical causation for enemy fighter movements did not exist; what remained instead was a range of possibilities for action given the random changes in direction presented. Boyd introduced the concept of getting inside your opponent's decision loop—a concept that has entrenched itself in everything from business to military tactics. The deliberate use of uncertainty had entered the real world.

3. BLACK SWANS

The study of uncertainty then challenged everyday reasonableness when a professor from Lebanon named Nicholas Taleb made some observations about the nature of randomness itself. A financial trader, Taleb noticed that randomness affected people in two distinct and different ways. In one environment, variations in data were cumulative, with one data point slightly influencing the total outcome, such as in a bell curve. In another environment, variations in data produced significant changes that drastically changed the total picture. In the first case, history crawled, in the second, history jumped. For example, a dentist would have to spend years drilling teeth to make his fortune, while a speculator could lose or win a fortune in a matter of minutes (Taleb, 2007). Randomness to a dentist could mean an unhappy patient, an event with negligible impact on his total earnings. To the speculator even one unpredictable event could spell fortune or disaster in a matter of minutes.

Why can't we predict some events? Taking insight from the observations of the mathematician Poincare, who saw that as the dynamics of a process increased, the error rate in modeling grew very rapidly (Taleb, 2007). As an example, he used the movement of billiard balls. While the process for predicting what would happen on the first hit was easy enough, to properly predict the ninth impact would require an account of the gravitational pull of the person standing next to the table!

Taleb called outcomes that carried significant consequences but appeared randomly, "Black Swans". In his book he discusses how a person's attempt to retrospectively explain why such an event took place creates a fundamental error. "We are," he states, "an explanation seeking animal who tends to think that everything has an identifiable cause …" When, in fact, what we are seeing may well be the noise of randomness, turned into information by our own self doing, and not a depiction of reality. According to Taleb (2007) Black Swans are a matter of luck "We tend to underestimate the role luck plays in our daily life but overestimate it in games of chance". The key to success is to maximize our ability to profit from good luck and minimize the outcomes of bad luck. 9/11, the Challenger accident, and the recent financial meltdown were all examples of Black Swans where our inability to acknowledge the existence of unpredictability created conditions that generated severe consequences.

As we look at the dynamics of landing aircraft, we see that the performance of the aircraft and the possibility of an overrun are affected by a few significant variables: point of touchdown, excessive airspeed, relative flight path, and contamination on the runway. These variables have a significant effect on the outcome of the landing. For example a long landing can increase the risk of an overrun by as much as 55% (van Es, 2005). Some form of variation is experienced in almost every landing. A runway with standing water, a slightly longer touchdown, and higher approach speed can add up to requirements for rollout distances well in excess of what is available, even on runways not considered challenging with reference to their field length.

The question is: how unpredictable is the average landing? The vast majority of the flying is anything but unpredictable. With backup instruments, backup systems, and technology ensuring the integrity of everything from my navigation to system status, there is little left to chance in the modern cockpit. Many of the overruns examined in accident reports occur following an approach coupled to the autopilot. So why do things seem to go so wrong from that point? To answer that we will first look at how randomness and risk are managed through the employment of a safety management system.

4. SAFETY MANAGEMENT

Safety Management Systems (SMS) have two core principles: safety management and safety assurance. The first step involves identifying relevant hazards and developing methods to reduce exposure to risk in a formalized manner; the second step assures quality in that process and provides an avenue for feedback. The SMS concept, while somewhat involved in its administration is basically a method for obtaining what is knowable to make decisions about risk and actively looking for the results of those decisions. To understand how this procedure relates to overrun risk, we will take a look at how this process is applied to runways that are 300 feet long.

In 2005 there was an overrun involving a B-737 at the Chicago Midway airport. The results of that investigation spurred major changes to the way the FAA looked at safety margins and aircraft performance methods concerning contaminated runways. To completely understand the challenges the average passenger jet landing present, we must look at the battle the airport was named for, the battle of Midway Island in WW II. Considered a major turning point in the war, it was an event completely defined by aircraft that landed on ships at sea. For these aircraft carriers, a landing airplane is not just a matter of safety but of national security as well. A detailed process was developed in the Naval Aviation community for defining, observing, designing, training, and assuring every single aspect of risk associated with a modern jet as it lands. Let us examine the process first from the view of safety management.

Safety management starts literally at the drawing board for a naval aircraft. The airframe has to be designed to land repeatedly at a 1200 fpm descent rate without damage while simultaneously transferring the forces of a tailhook throughout the airframe. The plane is designed to fly not airspeed but under a predetermined angle of attack that positions the airframe, landing gear, and tailhook at a precise angle to the runway. As most of you are probably aware, there is no flare in a carrier landing. The jet lands in the same manner as it flies the glide slope three miles out. The whole design produces an engineering constant called a “hook to eye”, distance that literally defines the vertical length between the end of the tailhook and the pilot’s eyeball.

Unlike the civilian ILS system, the radar tracking used to guide carrier-based jets provides a precision glide slope tailored to each specific type of aircraft. The ship then compensates for different “hook to eye” values of different aircrafts electronically. At three quarters of a mile from touchdown, when the aircraft is between 600 and 800 feet above the water, the pilot transitions to an optical glide slope. A Fresnel lens takes a light source and modifies it to produce a fine line of light that moves up and down a stack of lenses as the pilot’s eye moves above or below the glide slope. Since the light source produces a horizontal plane of light, that plane is then slightly rotated so that when that plane intersects the centerline of the ships landing area it produces a higher or lower glide slope to accommodate differences in “hook to eye” values.

The light source is situated so that it provides precision guidance until the aircraft’s glide slope literally intersects the runway. This places the tailhook before a selected steel cable that brings the jet to a quick but metered stop. For the pilot in the cockpit, visual cues to angle of attack above the glare shield facilitate a quick scan between the visual landing aid—called the “meatball”—his lineup on centerline (remember that the ship is constantly moving to his right due to the angled deck), and his all important angle of attack.

Runway contamination plays a negligible role in this case, once the aircraft touches down, there is an immediate engagement between the tailhook and a large steel cable engineered to bring the aircraft to a stop in 2 ½ seconds, while the engines are at full power. Crosswinds are kept in check merely by turning the entire landing field into the prevailing wind. These are luxuries that no civilian airfield would ever dream of.

So much for safety management, now the safety assurance part of SMS comes into play. On the side of the flight deck, there is a platform with special instruments and communication equipment where another carrier pilot, known as the Landing Signals Officer (LSO), stands. He controls the optical landing system, the arresting gear, and the status of the flight deck. Just as there are three attitude indicators on most jets (captain, first officer, standby) there are three LSO's for each landing event. In order to increase experience and training there is a controlling LSO, a backup LSO, and a senior or "Wing" LSO. Each one has the same radio and controls and can make the call to inform, direct, or wave off an approaching aircraft. The variables mentioned earlier are all carefully monitored and corrective instructions are given by the LSO throughout the approach. Airspeed (angle of attack) is identified by a three-colored light source in the approaching aircraft's nose gear; glideslope is monitored on a heads up display for the LSO; and point of touchdown is visually confirmed as the aircraft nears the flight deck. Tolerances measured in inches are observed and any pilot whose deviations stray too far is ordered to go around. The goal is to bring each aircraft to a point where normal variations in performance will not produce any adverse consequences that cannot be recovered from.

What's important here is that every aspect of the carrier landing is subject to a robust safety management/safety assurance process, from the extension of the landing gear to the final stop on the deck. As we compare this process to a civilian jet landing, we begin to see vast differences. A report by the National Aerospace Laboratory titled, "Running out of Runway," (van Es, 2005) analyzed thirty-five years of landing overrun accidents. The report described a "good landing" as the following:

1. A stabilized approach on speed, in trim, and on glide path.
2. An aircraft positioned to land in the touchdown zone.
3. A (runway) threshold crossing at correct speed and height.
4. A flare without rapid control movements followed by positive touchdown without floating.

Of critical interest to our discussion are deviations in approach path where variances in glide path add from 700 to 1000 feet to the desired touchdown point.

While the observations of the report are accurate, there are some practical issues with the employment of their definition of a "good landing." One of the main issues was the focus on one of the debates with the FAA among the members of the Takeoff and Landing Performance Advisory Rulemaking Committee in 2006: how to make a transition from an ILS glide slope to a 1500 foot touchdown point? The end consensus in the Committee was that, aside from Category III landings, all landings are essentially visual approaches. Any electronic glide path merely serves to get an aircraft to a point where a visual approach can be made. With careful avoidance of any association with phrases like "duck under," the consensus among the industry and FAA was that pilot training and techniques would take over to ensure the flare to touchdown occurred by the desired distance. For carrier operations, the mere thought of placing the entire ship's safety in the hands of pilot technique and training would be perceived as reckless. Lessons written in blood from years past have taught carrier aviators that only the most robust quality assurance process yields acceptable risk tolerances.

For the civilian airline pilot, this aircraft capability, airport capability, and level of oversight for each landing are simply not present. The visual glideslopes make no discrimination between a 757 and a regional jet. There is no wire to catch, only the friction available from the runway to stop the plane, often during changing conditions. Crosswinds can make pinpoint touchdowns difficult, and there is no one standing by the side of the runway to radio the pilot to go around should his touchdown point unexpectedly stray from planned parameters. In practicality, it is nearly impossible to achieve one hundred percent compliance with all the parameters required.

The point is that while the factors leading to a successful landing are essentially the same for the carrier approach as they are to the civilian field, the latter occurs in a virtual desert of safety management and safety assurance procedures when compared to carrier operations. While a touchdown from a specific glide path to a specific point at a specific energy state on a specific surface can be accomplished, it can never be assured.

It can never be assured unless there is a process in place to make sure that little is left to chance. In the US Navy, the operational support used to ensure the flight path of aircraft is enormously expensive and far from cost effective when compared to their civilian counterparts. Civilian aviation certification standards and established operating procedures prohibit the kinds of risk avoidance processes needed to ensure the level of quality control a carrier approach enjoys. The result is that all civilian landings must by definition carry a far greater degree of the unknown, the random, and even the improbable, than their sea based counterparts. Furthermore, such randomness has the capacity to cause drastic variations in performance. Therefore, any true approach to safety must address not only what we wish others to know, but also the limits on our knowledge and capabilities as well. Even our efforts on Cockpit Resource Management seem fairly shallow when compared to three specially trained and experienced pilots (LSO's) whose job is to specifically capture errors in plan continuation bias, perception based errors, and unforeseen events.

All the above discussions take for granted the fact that an airplane remains the same in every landing. For those of us who are professional pilots however, it is well known that this is not always the case. The modern cockpit is in the process of evolving and changing, and so are the procedures that surround it. Analog instruments have given way to flat panel displays, ground based navigation is now giving way to space based technologies, and the relationship between automation and flight is has steadily grown to place itself between the pilot and his/her aircraft. The result is a process of continuous change that itself can produce an environment for unexpected errors both while on approach and during landing.

A runway overrun must therefore be considered another example of a “Black Swan” event. While every incident may be explainable through hindsight, the existence of runway overrun incidents will forever remain unpredictable and carry great consequence. The conditions under which civil aviation operates dictate that uncertainty will forever play a role in the visual approach and the possibility of severe consequences will never be eliminated.

5. CONCLUSION

I do not wish to propose that we should ever stop trying to improve the odds in preventing landing overruns. There are still improvements in training, cockpit design, and pavement management that can be made. What is important is that the risks involved in aviation should be taken with our eyes open to the unpredictability inherent in the activity itself. To this end, there are some areas where our efforts should continue to be focused on. Here are my recommendations for improving safety in this area:

1. Runway Safety Areas will always remain vital to public safety. All runways need some form of arrestment condition beyond the paved surface. Such an arrestment could be a grassy overrun or other unprepared surface. However, if a hazard exists in this area, or if the area’s length is less than 1000 feet, the risk (or hazard) should be mitigated through some effort such as an EMAS bed.
2. A standardized touchdown point (1500 feet) should be established as a clearly marked and lighted reference position on all runways servicing turbine-powered traffic.
3. Standardized training for touchdown point control should be explicitly delineated in training manuals, taught on the line by check airmen, and practiced in the simulator during normal training cycles.

4. Approval criteria for ground based friction measurement devices should articulate accuracy and repeatability standards for common surfaces so that all devices read the same value for the same surface. In addition all operators should meet standardized training requirements for the use of such devices if their readings are to be reported to aircrews.
5. All aircraft should be equipped with a cockpit readout indicating actual braking performance during landings.

While these efforts will not totally eliminate the chance of landing accidents, I strongly believe that targeting the problem of reducing chance deviations while recognizing the existence of unpredictability as a fundamental constant in safety management, is essential. Only by changing current views to embrace the thought that uncertainty can never truly be eliminated, can we achieve the necessary levels of risk reduction.

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