IN QUEST OF THEORIES

FAILED LANDINGS IN BAD WEATHER

As a sign of tension between natural and economic forces, failed landings in bad weather represent an original risk situation. Natural factors play their part, as wind and rain, crucial variables, are hard to determine precisely at any one time. But economic factors are equally important: rerouting is expensive, competition is strong, runway ends (known as blast pads) are managed to the square yard, etc…

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Catastrophe (or risk) theory is a widely studied area. One might legitimately ask why pursue new developments in this already fairly well researched field. It so happens that failed landings in bad weather bear an interesting feature: natural variables have a high degree of indeterminacy, and have resisted man's many attempts to model them. Many hazardous human activities are, of course, subject to nature's whims, but a plane landing in bad weather is particularly exposed: we see airline pilots do not know how much rain sits on a runway in real time, but needs this input to determine the required landing distance.

When I learnt, through the media, of the August 2005 Air France flight overrun at Toronto airport during a storm, of the Airbus' destruction by fire and of the passengers' narrow escape, I asked myself what caused such an accident. I naturally thought of a technical failure. So it was with great curiosity that I looked forward in 2007 to the release of the Transportation Safety Board of Canada (TSB)'s inquest report. The media having briefly and fuzzily mentioned this report, I threw myself into it. I have read it and I have apprised myself of its technical aspects. I discovered a number of other, similar accidents that had occurred, and I consulted the reports of some of them. I have come to the conclusion that missed landing in bad weather is a particular type of disaster. They are the result of a tension between, on the one hand, poorly defined and costly to manage natural data, and, on the other, economic pressure. I will attempt, in my conclusion, to situate failed landings in bad weather within a larger typology of disasters.

THE TORONTO ACCIDENT: THE LANDING DISTANCE IN THE MANUAL EXCEEDED THE RUNWAY'S LENGTH

On August 2nd, 2005, at 11:53 a.m., Air France Flight 358 – an A340-313 Airbus – takes off from Paris for Toronto, with 297 passengers and 12 crew members on board. On final approach, the radar shows heavy rain: a heavy storm is hitting the airport. On landing, the aircraft cannot make a complete stop and overruns the runway. It ends up in a ravine and catches fire. Passengers and crew manage to all evacuate before the fire reaches the escape routes. Two crew members and ten passengers end up seriously injured during this accident.

Toronto airport's runway is 2 743 meters long. As the Air France Airbus lands on August 2nd, 2005, it weighs 190 tons (t) and the runway is wet with 6-7 millimetres of water – approx. ¼ inch – and is subject a 10-knot tailwind.

The A340-313 manual, provided by Air France to its pilot, indicates the required landing distance, given the aircraft's weight, the contamination of the run-

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way, tail wind speed, the airport's altitude and whether reverse thrust is used or not (cf. attached table).
The actual conditions of flight AF358 on August 2nd 2005 produce a recommended landing distance of 3 215 m. The runway length, at 2 743 m, is too short. Even given a more optimistic tailwind (of 5 instead of 10 kn), the recommended landing distance shortens to 2 811 m, still too long for the runway.
In addition, the aircraft flew over the runway's start 40 ft (12 m) higher than the norm, and reverse thrusters had been belatedly engaged. This lengthened the landing distance. Press articles attributed the overrun to these two facts. But even if both the runway approach and reverse thrusting had been executed at nominal levels, the onboard manual prescribed landing distance would still have exceeded the length of the runway.
Landing on a too short strip spontaneously brings to mind pilot error. However, this is not the case. In fact, Air France procedures did not incorporate an explicit recomputing of landing distances based on actual weather observed on arrival. "The crew was unaware of the landing distance required to land … on a contaminated runway"(1). At takeoff, the required landing distance was determined based on the anticipated weather on arrival. Should weather conditions deteriorate during the flight, no specific procedure existed for reassessing the landing distance required. After the accident, Air France made a point in its procedures to emphasize the importance of calculating the actual landing distance on arrival, according to the weather discovered on approach. Air France was far from being the only airline that did not include a specific procedure for determining the actual distance required on arrival. The US Federal Aviation Administration (FAA), concerned by repeated missed landings due to bad weather, issued a safety alert(2) in August 2006. It states that half the surveyed airlines have no procedures for assessing the landing distance required on arrival depending on weather observed in real time, even when conditions have worsened since takeoff. Even those who do take worsened conditions into consideration ignore runway contamination data. And most of those who do this on arrival assessment take no safety margin.
This procedural flaw is related to the fact that landings in very bad weather are subject to *a strong natural indeterminacy.* What I mean by this is that the data is particularly diverse, complex and shifting, when weather is at its worse. Moreover, *diffuse economic pressures* amplify risk. I will now examine both mechanisms.

But I must first define what I mean by "very bad weather". This encompasses what is called in air navigation convective weather (storms, wind, rain, monsoon) and milder conditions, albeit ones which make runways slippery (*e.g.* when melted snow is present).

RUNWAY CONTAMINATION

Uncertainty resides in two natural variables: rainfall and wind conditions. In aviation, a runway heavily disrupted by rain, snow or ice, is deemed to be *contaminated.* A first dimension of uncertainty is that the mere concept of *contamination* is fuzzy and multifaceted. I did not find a clear, mutually agreed upon definition. The Airbus A340-313 manual states a runway is contaminated if there is a layer of water of 3 mm or more. The Cessna Citation 551 business jet's threshold, on the other hand, is 0.25 mm. A 2 mm water layer contaminates a runway for the Citation, but not for the Airbus. The FAA, though anxious to bring some consistency to the subject, in its alert merely defines the contamination by listing contaminants – standing water, snow, slush, ice, sand – and defines a wet runway as uncontaminated. I consulted Air France expert Captain P. (an active captain with security duties); he believes contamination or not of a runway is determined as follows: moist if it has changed colour; wet if it has become shiny; *contaminated* if the water level is measurable. The Canadian Regional Airlines Fokker F28 manual holds other definitions, with different intervals. It distinguishes the following conditions: wet means under 0.25 mm of water; light rain, 0.25-0.76 mm; heavy rain, 0.76-2.54 mm; hydroplaning, over 2.5 mm(3).
Furthermore, though textbooks define contamination by water levels, these are actually impossible to measure. This is intuitively understandable: how can we determine, for instance, whether water is shallower or deeper than a quarter of a millimetre? France's Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA), the French body responsible for technical inquests into civil aviation accidents or incidents, explains: "We do not know how to operationally measure [runway] water levels"(4). According to Captain P., airport officials are careful not to announce runway water levels, for fear of assuming responsibility for a very random variable. Canada's

(1) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, Sortie en bout de piste et incendie de l'Airbus A340-313 F-GLZQ exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario)*, 2 August 2005, p. 133.

(2) Federal Aviation Administration, Safety Alert for Operators, Landing Performance Assessments at Time of Arrival (Turbojets), 31 August 2006, p. 4.

(3) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A00A0185, Sortie en bout de piste du Fokker F-28 C-GKCR exploité par les Lignes aériennes Canadien Régional, à Fredericton (Nouveau-Brunswick)*, 28 November 2000, p. 4.

(4) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien, Sorties longitudinales de pistes à l'atterrissage, p. 4.*

TSB concurs: "Few, if any, airports provide information on runway water levels(5) … For operations on wet runways, flight crews have no real way, such as runway water levels, to determine the condition of a runway before landing. "(6)
This is obviously a problem: aircraft manuals provide landing distances according to runway water levels. But since water levels are unfathomable, crews cannot determine the resulting landing distance. Canadian investigators point to a strong consensus among interviewed pilots stating lack of information on runway conditions due to significant rainfall represents a serious hazard.

landing distance of 1 379 m, assuming the just shovelled runway was simply wet. Unfortunately, within minutes, the runway was again covered with melting snow, increasing the nominal landing distance to 1 652 m, a greater length than the runway's(7).
The indeterminacy of the slippage rate may be enhanced by factors such as water accumulation caused by wind (contaminating some runway portions but not others), irregularly melting snow, leftover landing gear rubber and specific features (*e.g.* some runways, when wet, are particularly slippery, such as runway 35L at Congonhas Airport in São Paolo, Brazil, where a TAM Airbus overran the runway, and 199 people

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"In aviation, a runway heavily disrupted by rain, snow or ice, is deemed to be contaminated". Plane on the ground, in the rain, May 2000.

In addition, contamination is a rapidly evolving phenomenon. It may only take a few minutes for rain to change a runway from *wet* to *contaminated*. On November 28, 2000, a Canadian Regional Airlines Fokker with 42 passengers on board overran the runway at Fredericton, New Brunswick airport. The runway had been covered with melted snow, which had just been shovelled away. The crew computed a

died). This case provides another example of indeterminacy: an ungrooved, wet runway (like Congonhas) may be equivalent to a contaminated runway (grooves, though, are not an ideal solution, as snow and ice can embed in them).
However, contamination – a rapidly evolving, multifaceted phenomenon with neither a commonly agreed definition, nor a means of measure – has considerable

(5) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'Airbus A340-313 F-GLZQ, exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario) le 2 août 2005, p. 53*

(6) *Op. cit.*, p. 117.

(7) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A00A0185, sortie en bout de piste du Fokker F-28 C-GKCR exploité par les Lignes aériennes Canadien Régional, à Fredericton (Nouveau-Brunswick) le 28 novembre 2000*

impact on landing distances. Compared with a wet runway, 3 mm of rain increases a 190 t Airbus A340-313's landing distance by 900 m. Crossing the 0.25 mm threshold increases the Cessna Citation 551 business jet's landing distance by 423 m(8). A mere quarter millimetre of water increases by 423 m the landing distance!

Precipitation, besides making roads slippery, irregularly reduces visibility: therein lies another natural factor contributing to environmental uncertainty.

Sudden tailwind

A second natural and human element of strong indeterminacy in landings in bad weather is a possible sudden tailwind(9) of increased intensity. Sudden changes of wind speed and direction are characteristic of convective weather. Anyone experiencing a storm can attest to this. In the Toronto case, the aircraft was flying 300 ft high when its headwind suddenly transformed into a 10 kn tailwind (10). A BEA report on the overrun of a B747-300 at Paris, France's Charles de Gaulle (CDG) airport, stresses that wind was reported as calm during final approach, whereas a surge generating a 10 kn tailwind was actually recorded during this approach(11).

Furthermore, landing distances are very sensitive to wind conditions. Thus, a 10 kn tailwind increases a 190 t Airbus A340-313's landing distance by around 700 m. Given that the length of Toronto's runway is 2 743 m and that the windless landing distance on contaminated runways is 2 403 m, an extra 700 m is needed due to a tailwind push landing aircraft beyond the runway.

The large uncertainty of the wind brings is also notable in publications on the topic. BEA, in its report on CDG runway overruns, states "a training course defines calm wind as under or equal to 5 kn. The wind levels controllers give pilots during final approaches is averaged over 2 minute periods. The controller only communicates wind speed variations which deviate from the average by more than 10 kn. A 14 kn tailwind could thus be categorised as calm wind. Today's conditions [a CDG accident BEA is analysing] were close to this"(12). Captain P., whom I cited this BEA excerpt to, replied, surprised, that it was not possible for a 14 kn wind to be "calm wind". He may be right, but the mere fact that experts disagree demonstrates that this element is subject to a fair measure of natural and human uncertainty. According to the Canadian report on the Toronto accident, "the crew got wind speed and direction from the aircraft navigation monitor, which indicated a 15-20 kn, 70-90° [*i.e.* starboard] crosswind." (13) Shortly after, "the wind changed direction and … the tailwind component rose to 10 kn."(14) BEA concludes "tailwind conditions during approach and landing are not always broadcast.(15)"

The uncertainty related to wind in convective weather is also due to how wind is managed. If a tailwind component suddenly appears on final approach, and assuming that pilots are made aware of it (which, as we have seen, is not always the case), they must quickly review the landing phase – in particular, the landing distance – at a time when their workload is intense. BEA, in the same CDG runway overrun analysis, writes "The crew, which had acknowledged an important tailwind component on initial approach was found not to have taken this component into account in managing the final approach. They attribute this lapse to their workload…"(16)

The complexity of wind is accentuated by an effect known in aviation as wind gradient, or wind shear. This is the sudden change in wind direction that produces strong tailwinds. These, instead of speeding up the aircraft, counteract its lift. Pilots must maintain speed at a level low enough not to increase the landing distance, knowing that a speed too low will cancel the aircraft's bearing pressure if shear occurs. In the Toronto case, there was tailwind but no shear. But we can assume that the crew had the risk of shear in mind.

Diffuse economic pressure

In the field of approaches and landings in very bad weather, several facts lead us to believe there exists diffuse economic pressure, which increases the risk of accidents.

First, there is a tendency to try to land rather than re-engage thrusters and opt to change airports in case of very bad weather. I venture that commercial and economic considerations are not unrelated to this behaviour.

(8) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.*, p 4.*

(9) *Vent latéral ayant une composante arrière.*

(10) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'airbus a340-313 F-GLZQ exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario) le 2 août 2005, p.125.*

(11) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.*, p 6.*

(12) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.*, p 6.*

(13) *Bureau de la sécurité des transports du Canada, Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'airbus a340-313 F-GLZQ exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario) le 2 août 2005, p. 5.*

(14) Op.cit.*, p. 5.*

(15) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.*, p. 8.*

(16) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.*, p. 7.*

One fact that illustrates this is provided by MIT research(17), which shows a marked difference in pilot behaviour on entering convective systems, depending on whether the aircraft is en route or in final approach. The difference between the number of storms entered into en route and in final approach is significant. Storms are rated on an ascending intensity scale of 1 to 6. Pilots almost never enter 3-, 4- or 5-intensity storms en route, whereas they enter these hundreds of times in approach. Of 281 flight approaches that entered 3-, 4- or 5-intensity storms, only 10 % were rerouted. The Toronto accident report puts forward as an explanation that avoiding bad weather in final approach is more costly than avoiding bad weather en route as it could result in either an aborted approach or a rerouting. A further element reinforcing this hypothesis is the fact, reported in MIT's survey, that aircraft are more likely to enter bad weather when they are at least 15 mn behind schedule.

Another element related to commercial and economic pressures is fuel management. In case of very bad weather, common sense would suggest that pilots should have all the fuel needed to wait out the storm, attempt to land again, and then opt to reroute with comfortable reserves to another airport in case bad weather conditions persist. But this does not happen. Fuel need we mention – is expensive, and must be saved. This objective can lead pilots, when criteria justifying a change of airports (and hence increased fuel consumption) are not obvious (as is often the case in convective weather), to decide to land at the intended destination. Rerouting may also be risky. The ill-fated Toronto flight crew had decided that, if its approach failed, it would reroute to Ottawa. The minimum fuel required to reach Ottawa is 4.5 t, to which must be added a mandatory final reserve of 2.8 t as a provision for a 30 mn hold above the airport, *i.e.* a total 7.3 t. The plane actually landed in Toronto with 7.63 t of fuel, an amount sufficient for rerouting. However, there is a rule stating, if the fuel on landing is less than 4.2 t (or 1.5 times the required final reserve), the crew must report to air traffic control a *minimum fuel* condition. This announcement does not give priority treatment to the aircraft, but does signal to air traffic control that an emergency might occur if landing of that aircraft were delayed. Procedures state pilots should declare an emergency if fuel is below final fuel reserves (under 2.8 t). So, if the crew had opted for Ottawa, they would have announced a *minimum fuel* condition. And should any slight delay have occurred due to weather or traffic, the crew would have been forced to declare a fuel emergency. Because of fuel management, a rerouting to Ottawa was a far from snug solution. Furthermore, any rerouted flight is likely to encounter a traffic jam as other similarly redirected flights converge on the backup airport.

Commercial and economic pressures naturally include passenger handling in case of rerouting. The Toronto flight crew's file included a factsheet indicating that an Ottawa-Toronto coach trip, the planned contingency in case of rerouting, would last five hours, a major inconvenience. This five-hour duration had been circled on the factsheet. There is no evidence that this hindered the pilot's decision to fall back on Ottawa, but one can legitimately assume he had this in mind when the decision was made to try and land in Toronto.

Three other factors with commercial and economic dimensions affect landing conditions: the airport's operation (it was not closed), the official landing distance and, finally, the length and other features of the runways.

The airport operator is responsible for shutting down an airport or part of its infrastructure. All interviewed airport officials in Canada, the US and France said they do not expect an airport to be shut down due to wind, rain or storms. Air traffic control's responsibility is solely to ensure runways are free of obstructions. Only specific winter conditions (snow, sleet) warrant the shutdown of one or several runways. The ultimate decision to proceed with an approach and landing lies with the pilot. In a competitive system, it is natural for airports to choose to remain open when weather is convective. A shutdown during storms, wind or heavy rain would place an airport at a competitive disadvantage. Russian airports, less subject to competition and the profit motive (at least until recently), famously tended to close whenever weather was bad. Keeping open an airport in case of convective weather, for economic reasons, increases the propensity to try and land at it. All the more so, since, according to this report, pilots, including those involved here, are under the – mistaken – impression that airports shut down in case of very bad weather, thus signalling by still being open that attempting to land is safe.

As for landing distances, the starting point is the official distance provided by the aircraft manufacturer, known in the industry as *unfactored distance*. This is the landing distance under ideal conditions: a dry runway, no wind, an approach carried out with maximum performance… Manufacturers, in order to sell their aircraft, have an interest in registering the shortest possible unfactored distances. But the registry conditions are different from operational requirements. In practice, longer, usable landing distances, called *factored distances*, are calculated according to real conditions, either by extrapolation or through trials, and by adding safety margins. But unfactored distances, unrealistic and commercially motivated though they may be, are nonetheless an important reference.

(17) D.A. Rhoda et M.L. Pawlak, *An Assessment of Thunderstorm Penetrations and Deviations by Commercial Aircraft in the Terminal Area, Lincoln Laboratory*, Massachusetts Institute of Technology, Lexington, Massachusetts, 3 June 1999.

Contrary to what we might imagine, many if not most runways are not particularly long. Toronto airport's runway 24L, beyond which the accident took place, measures 2 743 m. BEA studied three overruns (18) at CDG runway 08R, whose length is 2 700 m. "At CDG, in particular, runways normally dedicated to landings are the shortest (2 700 m)"(19). These distances are fine when the runway is dry or a little wet, and wind conditions favourable. But in the cases of contamination or tailwinds, the difference between required landing distance and actual runway length shrinks considerably. Thus, contaminated with a 5 kn tail wind, a 190 t Airbus A340-313 needs 2 784 m to land (with reverse thrust). This figure is closer to Toronto 24L's 2 743 m and CDG 08R's 2 700 m. Let's now focus on Perigueux, France's runway, which suffered an overrun analysed by BEA(20). Its length is 1 620 m. Whenever there is over 0.25 mm of water on the runway, the landing distance of a Citation rises to 1 445 m. That leaves just 175 m between theoretical full stop and runway end, assuming no tailwind. Furthermore, economic considerations may lead to worsening of runways. On July 17th, 2007, the TAM Airbus A320 airline Congonhas runway overrun resulted in a death toll of 199. The runway was deemed slippery in wet weather, but grooving had been suspended in favour of maintaining traffic. Furthermore, the runway lacks compulsory blast pads.

Economic considerations lead to employing the longer runways exclusively for takeoffs and the shorter ones for landings. Flows may thus be separated; and airports, be more operationally profitable. But this does not help landings in bad weather.

Nonrobustness and weak safety margins

Landing in bad weather suffers from indeterminate natural and economic pressures from which ensue a lack of robustness and the thinnest of safety margins. An excellent example of nonrobustness is the inconsistent reasoning about landing distances between wet and contaminated runways. The landing distance on dry runways is unfactored distance times 5/3 or 1.67 (*i.e.* the unfactored distance is only 60 % of the runway). Wet runways add 15%. But when runways are contaminated, the reasoning changes: contaminated runways trials are conducted and observed landing distances are increased by another 15 %. In other words: when runways are wet, the margin is 82% (67% + 15%) compared to dry runway trials; and when the runway is contaminated, it drops to 15% compared to those conducted on contaminated runways. Accustomed to comfortable margins of 60% or 82% for dry and wet runways, pilots, suddenly faced with contaminated runways and no more than a 15% margin, become confused. After the Toronto accident, Air France decided to focus its training, on the logical distinction made between wet and contaminated runways margins.

This lack of robustness is illustrated by other facts: the lack of specific procedures dictating calculation of required landing distances depending on weather on arrival (a flaw Air France recently corrected); the many definitions of runway contamination; the reference to runway water levels even though they are not measured (or even measurable), much less communicated to flight crews; the unfounded belief among pilots that an airport might be closed in case of rain, wind or storms; the ongoing debate on inclusion or not in manuals of reverse thrusters and/or braking systems engagement in setting required landing distances; the complexity of the landing distance tables; and the use of braking performance information from the immediately previously landed aircraft, with different features (weight, size); etc.

To cite just one of many recent examples of nonrobustness: the manual in the hands of the crew of the Fokker which, due to melting snow, overran its runway in Canada on November 28th, 2000, indicated landing distances for a variety of weather conditions – compacted snow below 15 °C, compacted snow above 15 °C, packed and sanded snow, snow in patches, wet ice, ice below 10 °C, sanded ice – but none for melting snow (which is surprising for Canadian domestic routes).(21) On the other hand, the manual in the Airbus that crashed in Toronto indicates landing distances for wet snow and slush.

Significantly, there is no standard, simple rule that would allow crews to decide whether to divert in case of very bad weather landing conditions. Yet that is what BEA recommends in its Toronto accident report. "BEA recommends that civil aviation authorities establish clear standard conditions restricting approaches and landings in convective weather"(22). Setting such a rule faces a double challenge. Variable indeterminacy is such that any formal rule will stray strongly to the side of caution to cover all possible contingencies, and therefore will set very low thresholds above which the aircraft must reroute. And that is where economics enter the picture: any airline or country that sets very low rerouting thresholds puts

(18) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op. cit.*, pp. 4-8.*

(19) Op. cit., *p. 8.*

(20) Op. cit.*, p. 3 et 4.*

(21) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A00A0185, sortie en bout de piste du Fokker F-28 C-GKCR exploité par les Lignes aériennes Canadien Régional, à Fredericton (Nouveau-Brunswick), le 28 novembre 2000.*

(22) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'Airbus A340-313 F-GLZQ exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario) le 2 août 2005, p.132.*

itself at a comparative disadvantage. The combination of strong natural uncertainty (unpredictable air and water) and diffuse economic pressures leads to a lack of resolution. Hence the absurdity of, for instance, providing in onboard crew manuals landing distances, depending on real time water levels that are unavailable in real time.

Many facts show, moreover, the razor-thin nature of safety margins. We saw above the landing distance of an Airbus A340-313 left no margin of error between a full stop and the end of the runway on several runways, such as Toronto 24L or CDG 08R, when contaminated. A runway may be slippery, and the estimated landing distance accurate, compared to the actual runway length. But the margin of error is so low any ulterior unfavourable factor is enough to nudge the aircraft beyond the runway: any (however minute) tailwind, a few seconds' delay engaging reverse thrusters, an ever so slightly too high approach, etc. The FAA recommends a 15% safety margin on actual landing distances. But 15% is very little leeway. Test pilots establish landing distances in tests that stress the aircraft to the extreme (even damaging them) in order to minimise braking distances, leading to commercially unrealistic and inapplicable conditions. Moreover, many hazards increase landing distances by an order of magnitude at least equivalent to the 15% safety margin. For example, for an A340-313, a sudden 5 kn tailwind increases the landing distance by 15%; the absence of reverse thrust, by 11% (the FAA recommends landing distances be boosted by 20% in the absence of reverse thrust(23)). An insufficient landing distance because of bad weather caused an accident in Chicago a few months after Toronto. This time, the landing distance had been computed with the presence of snow on the runway acknowledged, but under the assumption of a timely reverse thrust, *i.e.* with no safety margin. The reverse thrust was engaged several seconds late so the runway's length proved inadequate. In the case of the Fokker overrun at Fredericton Airport, there was a 175 m margin distance between the landing distance on wet runways and the runway length. As the runway was not just wet, but covered in slush, 273 m were needed: the aircraft overran the runway.

One can also review the issue of margins by examining the blast pads at the end of runways. International standards warrant a 150-m long, obstruction-free area, at the end of runways. But 150 m, in terms of landing distances in adverse conditions, especially for the shorter runways, is very little. As a matter of fact, the FAA (which studied 12 years of overruns) found most aircraft overran by 305 m (1 000 ft) or less (the margin the FAA now requires). That is double the 150 m margin.

As BEA pithily remarks its own report on overruns, "These regulatory margins were set to take sundry variables into account and no correspondence with operational realities exists"(24).

The frequency of bad weather landing accidents

In cases of landing in very bad weather, the indeterminacy of natural factors and diffuse economic pressure, with their lack of robustness and of sufficient margins, inevitably result in frequent accidents (relatively speaking, that is: air travel is generally very safe). TSB does not beat around the bush: "TSB Research conducted following this [Toronto] accident has clearly shown that entering convective weather in the final approach and landing phases was a widespread industry practice[…] As a result, approaches and landings accidents caused by convective weather occur regularly throughout the world"(25). National Geographic Channel ("Air Crash") reports 37 runway overruns in 2005, linked to conditions similar to Toronto's accident.

Lists, though not exhaustive, illustrate this trend. TSB cites six cases in companies other than Air France. BEA cites five other cases in its article on runway overruns(26). There are also recent cases: July 17th, 2007, São Paulo(27) (TAM Airbus with a death toll of 199); January 4th, 2008, Deauville (Atlas Blue Boeing 737 overrun); March 3rd, 2008, Hamburg (the wing of a Lufthansa Airbus A320 hits the runway); and September 5th, 2008, Limoges (Ryanair Boeing 737 overrun).

Theoretical musings

Every disaster is the combination of many variables. I propose, however, to distinguish the former according to which of the latter dominate in the outcome. For starters, one can discern *essentially natural disasters.* The indeterminacy of natural phenomena is overwhelming. A typical example is tornadoes. Their appearance is extremely sudden; their path, unpredictable; their power, cataclysmic. Forecasts exist but are inefficient, and protection against wind strength is limited.

(23) Federal Aviation Administration, Safety Alert for Operators, Landing Performance Assessments at Time of Arrival (Turbojets), 31 August 2006, p. 4.

(24) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit., *p. 8.*

(25) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'Airbus A340-313 F-GLZQ exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario) le 2 août 2005, pp. 89-90.*

(26) *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, Incidents en transport aérien,* op.cit.

(27) Accident worsened by a reversed thrust and the absence of a safety zone at the end of the runway.

Second, one can identify *dominantly technological disasters*. These are Charles Perrow's "accidents"(28). Technological processes are so complex that anticipating every possible outcome is impossible. Inevitably, sooner or later, an unforeseen technical event occurs, with side-effects and cascading, chain reactions that lead to a catastrophe. Some time ago, in the UK a long-haul carrier was forced to land before reaching the runway, because both engines suddenly failed. Engineers do not understand what happened. A bug in the engine management software is suspected. The incident made no victims, but I would have labelled it a dominantly technological disaster, had it not been a near miss.

Dominantly economic disasters are a third category. Interviewed on her contemporary vision of unreliability factors, Karlene Roberts(29), one of the founders of the school of high reliability organisations, enumerated economic factors. For her, organisational savings, so fashionable today, introduce a brittleness in organisations that undermines high reliability: human capital downsizing, training cost-cutting, outsourcing (inter-organisation links are weak points), responsibility-weakening, extreme streamlining, and activity breakdowns into competing units. The train wrecks the UK experienced a few years ago are to my mind typical dominantly economic disasters.

In conclusion, *dominantly organisational disasters* merit mention. An emblematic case is the Challenger shuttle explosion. Interpretations vary. Diane Vaughan(30) sees it as the effect of what she calls a *normalization of deviance*. Christian Morel(31) insists more on the loss of cognitive and teleological cues, which plunge organisations into the absurd. This case could also be studied from the standpoint of Crozierian sociology (the bureaucratic phenomenon, conflicts of interest, vicious circles, etc.). Whatever the approach, the organisation is, here, the architect of its own undoing(32).

Finally, let us return to the cases studied in this article: failed landings in very bad weather bear two dominant factor sets, natural and economic. Nature's influence is central, because wind and precipitation are crucial variables, difficult to determine accurately in real time. But economics is no less important: rerouting is a costly affair, competition is intense, and runway operating margins are razor-thin.

Organisations faced with dual-dominance catastrophe risk (natural and economic) are subject to a dilemma that is reflected in their behaviour: nonrobust solutions, insufficient wiggle room, partial measures, poorly binding arrangements, etc.

Take for example the decision to either enter a storm front on final approach or reroute. On the one hand, rerouting has a value. A member of the US National Transportation Safety Board (NTSB) said, after an accident in Little Rock, similar to the one in Toronto "We do not want this here" (*i.e.* we do not want to see planes landing in a thunderstorm here). At Air France, the training curriculum prescribes re-engaging thrusters (and, probably rerouting). But on the other hand, we observe the opposite trend of limiting rerouting. An aviation symposium in Ottawa included a working group on fuel economy(33). The unlikelihood of weather-motivated rerouting was estimated at "1 in 4 000 flights" (!), totally at odds with the stance of limiting landings in very bad weather, landings pilots tend to practice too much. Another slide quirkily illustrated this policy on rerouting waffling: first was stated that "fuel economy measures are a necessity" then, second, "safety always comes first".

Another example of this dilemma: whenever a landing accident occurs due to very bad weather, investigators forcefully reiterate, every time, that clear rules must be set limiting attempts to land under these conditions. This type of conclusion is present in the inquest reports on the following landing accidents:

– Little Rock, 1999 (American Airlines). An NTSB member: "We really need a buffer zone around storms and standardisation… "(34).

– Bangkok, 1999 (Qantas). The Australian Transport Safety Bureau "recommends all Australian high capacity jet airline operators set up procedures ... ensuring flight crews are properly equipped for approaches and landings on wet and contaminated runways "(35).

– Cayenne, 2001 (Air France). "BEA recommends that France's Direction Générale de l'Aviation Civile [DGAC] ensures operators' instructions [to their flight crews] to carry out approaches and landings in stormy conditions be sufficiently clear and precise "(36).

(28) Charles PERROW, *Normal accidents*, Princeton University Press, Princeton, 1984, 451 p.

(29) "An interview with Karlene Roberts", Interview by Mathilde Bourrier, *European Management Journal*, Vol. 23, N°. 1, February 2005, pp. 93-97

(30) Diane VAUGHAN, *The Challenger Launch Decision*, The University of Chicago Press, Chicago, 1996, 575 p.

(31) Christian MOREL, *Les Décisions absurdes*, Gallimard, Paris, 2002, 309 p.

(32) Voir notamment : Karl E. WEICK, "The collapse of sensemaking in organizations : The Mann Gulf Disaster", *Administrative Science Quaterly*, December 1993, 38, 4, pp 628-652.

(33) Richard SOWDEN, *Atelier sur les mesures opérationnelles visant aux économies de carburant*, Ottawa, 5-6 novembre 2002.

(34) "Inadequate Standardization and Tired Pilots Emerge as Top Issues in Crash Investigation", *Air Safety Week*, site web, 29 October 2001.

(35) Australian Transport Safety Bureau, Investigation Report 199904538, Boeing 747-438, VH-OJH, Bangkok, Thailand, 23 September 1999.

(36) *BEA, Rapport. Incident survenu le 25 mai 2001 sur l'aérodrome de Cayenne-Rochambeau (Guyane) à l'Airbus A340-311 immatriculé F-GLZC exploité par Air France, 25 Mai 2001, 71p.*

A340
AIR FRANCE
OA.NT

Performances Particulières (313)
DECOLLAGE ET ATTERRISSAGE SUR PISTE CONTAMINEE

TU 04.02.50. 13
25 DEC 03
313

VOLETS FULL

- Tableaux valables pour :
  - . 0 ft d'altitude pression
  - . pour toutes températures ≤ 40°C
  - . vent nul
  - . sans utilisation des inverseurs et sans autobrake.
  - . VAPP = VLS + 5 kt
- **Interpolations** sur masses et épaisseurs **obligatoires.**
- **Extrapolation interdite.**

LONGUEURS DE PISTE NECESSAIRES A L'ATTERRISSAGE (mètres)

ETAT DE LA PISTE			Masse atterrissage (t) 130	150	170	190	210	230	250	270
Eau	3 à 6 mm		2060	2160	2350	2690	3010	3320	3620	3890
Eau	13 mm		1980	2010	2180	2470	2760	3050	3330	3730
Neige poudreuse	Neige mouillée	Slush								
15 à 51 mm	4 à 13 mm	2 à 6 mm	1980	2000	2110	2330	2600	2950	3330	3730
-	25 mm	13 mm	1980	2000	2110	2330	2590	2950	3330	3730
Neige tassée ou Glace (*)			1980	2000	2110	2330	2590	2950	3330	3730
Glace (**)			3350	3540	3810	4220	4640	5000	5300	5590

(*) Glace avec coeff. frottement > 0,25 ou freinage reporté = MEDIUM ou GOOD
(**)Glace avec coeff. frottement ≤ 0,25 ou freinage reporté = POOR ou UNRELIABLE : **Atterrissage INTERDIT sauf cas d'urgence.**

CORRECTIONS (%)

Corriger les longueurs nécessaires d'atterrissage des tableaux ci dessus en fonction des conditions suivantes:

VAPP = VLS		- 3 %
Altitude pression aéroport	Par tranche de 1000 ft au-dessus de 0 ft	+ 5 %
Vent arrière (pour 5kt)	Neige tassée	+ 10 %
	Autres contaminants	+ 15 %
Utilisation des 4 inverseurs	Glace	- 26 %
	Autres contaminants	- 10 %

Specific performances. Contaminated runway takeoffs and landings (Air France Operation Manual, December 25, 2003)

– Toronto, 2005 (Air France). TSB "recommends DGAC and other civil aviation authorities establish clear standards limiting approaches and landings in convective weather"(37).

– Chicago, 2005 (US Airline). The FAA issued a safety alert recommending safety margins and standardized procedures.(38)

But today there is still no global standard for accurate, clear and operational restrictions to landings in very bad weather.

Consider the case of dangerous dog attacks. These are accidents rather than disasters, but they are perceived as the latter by public opinion, because of their horrible and repetitive nature. These accidents are also characterised by dual-dominance: natural and economic. On one hand is natural indeterminacy: which breeds truly are dangerous, what mitigating effect dog training has, what rouses dogs, etc. To effectively check this indeterminacy, many major restrictions appear to be required (prohibition of many breeds, compulsory training and licenses). On the other hand is economic pressure, in consumerist form: owners are reluctant to accept curbs on their choices. This tension shapes collective behav-iour: adopted measures are flawed and ineffective; professional dog breeders issue conflicting statements; every drama produces reactions, until the froth fades…

Coming back to landings in very bad weather, one may ponder how this topic will evolve: the issue will obviously not go away; storms and rain will not stop; and air traffic tends to increase. To allay the tension between the two dimensions of the issue – natural indeterminacy and economic pressure –, something has to give. Technical solutions can address natural indeterminacy. Standardized friction coefficients could be defined, and measured in real time on each runway: we have the technology. Contamination could be objectively measured. Landing distances – for every individual aircraft – could then be computed, based on actual contamination coefficients. Blast pads could be fitted with braking systems, similar to those designed for trucks at the bottom of steep gradients (on loose soil in which wheels sink). Some runways are already thus equipped and these systems have been of use in overruns. A check on economic pressure, to overcome competition concerns, could take some form of international governance. Indeed, the aforementioned technical solutions are viable only if all airports and airlines comply with them, because non-compliance brings a competitive advantage, cost- and trade-wise (less regulation, less infrastructure, less rerouting). This can only be steered by the International Civil Aviation Organisation. ■

(37) *Bureau de la sécurité des transports du Canada, Rapport d'enquête aéronautique A05H0002, sortie en bout de piste et incendie de l'Airbus A340-313 F-GLZQ, exploité par Air France, à l'aéroport international de Toronto/Lester B. Pearson (Ontario), 2 août 2005, p. 132.*

(38) Federal Aviation Administration, Safety Alert for Operators, Landing Performance Assessments at Time of Arrival (Turbojets), 31 August 2006, 11p.