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# focus

ON COMMERCIAL AVIATION SAFETY

WINTER 08


The official publication of the United Kingdom Flight Safety Committee
ISSN 1355-1523

AIRSPACE
& SAFETY
INITIATIVE

# goodbye RIS and RAS

from **12 March 2009** the UK's Air Traffic Services Outside Controlled Airspace change.
You can get find full details and an interactive tutorial guide to the new services at
**www.airspacesafety.com**

UK CAA licensed commercial pilots and controllers have been sent a CD guide in the post and private pilots' CDs are being despatched in January 09. (MoD staff will receive details direct from the MoD)

in the meantime the existing ATC services outside controlled airspace remain available.

**The Airspace & Safety Initiative (ASI) is a joint CAA, NATS, AOA, GA and MoD effort to investigate and tackle the major safety risks in UK airspace.**

# Contents

The Official Publication of THE UNITED KINGDOM FLIGHT SAFETY COMMITTEE ISSN: 1355-1523 WINTER 2008

**FOCUS** is a quarterly subscription journal devoted to the promotion of best practises in aviation safety. It includes articles, either original or reprinted from other sources, related to safety issues throughout all areas of air transport operations. Besides providing information on safety related matters, **FOCUS** aims to promote debate and improve networking within the industry. It must be emphasised that **FOCUS** is not intended as a substitute for regulatory information or company publications and procedures.

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*Front Cover Picture: Photograph by Mike Moores.*
*British Airways B747-400 landing on Runway 27 left at London Heathrow Airport, immediately before the inaugural Airbus A380 arrival.*

# Is Flight Safety Our Primary Concern or Our Primary Target for Savings?

by Rich Jones

**Along with most industrial sectors, the commercial air transport sector is beginning to suffer a serious downturn in business which has been created by the loss of confidence in the economy generally, the lack of flexible and reliable financial support and an uncertain and variable oil price. In addition, the industry, which has always been extremely competitive has also to operate in a global market where the population has become increasingly aware and protective of the environment and where political interference and legal scrutiny bring yet further pressures from both sides of the aviation argument. Nevertheless, the airline sector continues to perform with remarkable resilience and dynamism; it has seen and successfully dealt with many of these challenges on many occasions in the past 40 years or more, although it has probably never had to face them in such depth, coincidence and complexity as it is having to do today.**

Why should FOCUS, a magazine primarily concerned with aviation safety, wish to rehearse the many pressures being simultaneously exerted on the modern airline business in 2008 – they are very familiar to most of us and clearly a source of serious concern. The rationale for doing so is to set in context the obvious temptation in these difficult times for the flight safety message to be pushed down the priority list and off the agenda. Significant pressure to quickly reduce costs by shedding those resources and people dedicated to delivering safety, whilst continuing to utter the 'safety is our primary concern' mantra can be seen an easy win for the bottom line.

However, there is strong business argument against the initially seductive approach of reducing the sector's investment in aviation safety in order to transfer the weight of financial effort to areas which appear to contribute more directly to business survival. For a start, financial worries about the future are not the exclusive territory of Chief Executives and Finance Directors. They permeate the minds and thoughts of the entire workforce of any airline, particularly at times like these. These distractions, and the potentially negative effect on an individual's concentration on the job in hand, be they pilot, cabin crew or engineer, will tend towards errors and mistakes being made more easily and more often.

During such times of personal pressures, it must be worth considering greater emphasis on supervision, communication and support as a business-positive incentive to counter potentially extremely costly errors – it is an investment which could pay dividends to the bottom line in an industry where mistakes can be expensive, if not business threatening.

Training is another area for careful consideration during these financially taut times. Over recent years, both initial and continuity training courses have been steadily squeezed in terms of content and time allotted, on the basis of the training provider's assurances that simulation and training aids have become more effective and therefore much more cost efficient. Yet, over a similar period, commercial aircraft have become highly automated and somewhat easier to fly and operate – at least whilst they remain fully serviceable. However, the on-board systems to provide the necessary situational awareness and to enable the aircraft to be flown accurately in ever more congested airspace have become increasingly complex when things start to go wrong.

Nowadays aircraft, and the systems that make them simple to operate, are becoming more reliable but this is tending to drive us towards becoming increasingly reliant and trusting of them. In the rare event that they fail, hopefully with all the clues to signal such a failure, then the necessary depth of training must still have been provided in order that the accurate diagnosis is reached and the appropriate corrective actions are deployed through the application of sound knowledge and airmanship; training is the key element which delivers this capability and ensures safe endings occur and not accidents.

Despite many years of exchanging aviation safety information, and the same mistakes being made time and again, the number of incidents in today's sophisticated, risk-aware, commercial air transport sector remains more than sufficient to justify the continuing need for the constant reiteration of aviation safety lessons. For example, as winter approaches the perennial threat of aircraft icing will be upon us and there will undoubtedly be instances of loss of control caused by insufficient attention being paid to it. Does your training include seasonal reminders of the importance of appropriate measures to counter the effects of ice? The aviation safety website – Skybrary - offers up some sound advice to counter aircraft icing that you may wish to consider!

Turning from an old chestnut to a more recent phenomenon; the introduction of more efficient fuel loads is making an important contribution towards the bottom line, but do your pilots have a clear understanding of the diversion criteria for the airports and air traffic service providers they are using? Should circumstances of weather or sudden runway closures conspire against them, do they know enough about the constraints and assumptions which those supporting the aircraft's safe operation will apply, in order that sensible decisions on fuel uplift and diversions are being taken?

## UK FLIGHT SAFETY COMMITTEE OBJECTIVES

- To pursue the highest standards of aviation safety.
- To constitute a body of experienced aviation flight safety personnel available for consultation.
- To facilitate the free exchange of aviation safety data.
- To maintain an appropriate liaison with other bodies concerned with aviation safety.
- To provide assistance to operators establishing and maintaining a flight safety organisation.

# The 'Basics of Safety'

by Steve Hull, British Airways

**As I leave British Airways after a 38 year career that has spanned engineering, flying and for the last sixteen years safety, it could be assumed that I would have seen many changes in aviation, but in actual fact there have been remarkably few.**

I joined, as it was then British European Airways on 2nd September 1970 the same year that the Boeing 747 took to the sky. The Boeing 747, affectionately known as the 'Jumbo Jet,' held the passenger capacity record for 37 years until it was surpassed by the Airbus A380 last year. A year before, in 1969 Concorde made her first test flight and in 1973 supersonic passenger travel became a reality.

So what changes have there been, Concorde is a distant memory and supersonic passenger travel has become a dream that once again appears to be years away, the world has realised the effects of carbon emissions and the push is to try to produce aircraft that fly 'on thin air instead of, in thin air.' Airline passenger travel is more available to the majority as opposed to the minority and most importantly aviation safety is every airlines No.1 Priority.

It would be inappropriate of me to 'wax lyrical' over aviation history, but more appropriate to concentrate on today, and in particular aviation safety. So what progress has been made? Most airlines major focus is on data collection and information exchange. This means that there are probably millions of pieces of data that describe past events. For some airlines the data certainly helps in understanding the state of the operation, but as has been quoted before 'data is important and will help, but data driven safety only helps to fix what already went wrong.' Data has never prevented an accident, in fact the collection of data is reactive and of course it is proactive safety management that is preferred.

How easy is it to be proactive as a safety professional? Being proactive in safety management you attempt to identify the latent conditions and reduce them, then equally you will reduce the incidents, serious incidents and ultimately the accidents. This is a great theory, but in practice there is reluctance for airlines and also non-airline organizations, to take steps to identify and then remove the latent conditions. Airlines response is usually based on the outcome of an incident, as there is no doubt that the smoking hole will be met with an immediate and impressive response, as history shows us. A near miss will never get the same company reaction as an accident, although the process leading to both events may have or will have been identical.

As safety professionals it then becomes our duty to constantly press for the latent conditions firstly, to be recognized and then, acted upon. If latent conditions are not recognized then incidents must be highlighted. The danger of course occurs if it is only the serious incidents that are reacted to. It takes a very mature and enlightened company to put resources into searching out and remedying latent conditions, as this is the area where the most value will be obtained. Airline safety is primarily identifying areas of concern and then mitigating them, it cannot be based solely on 'gut feel.'

As I have quoted before, airlines have short memories when it comes to accidents. This is mainly due to our own success story. Aircraft are safer, pilots and engineers better trained and ATC is more sophisticated. The result is fortunately we do not have accidents often enough to become proficient in accident response etc. Unlike in recent history when it was expected that an airline would lose an aircraft or two, so extra were ordered.

So as a Safety Manager how are you expected to act? Having had first hand experience, it is not a natural flow or a simple slip into automatic mode, as an old colleague once described. It is more a case of intuition. Arriving at an accident site is surreal, particularly if the accident is 'one of yours.' How are you trained to react, or more importantly how do you react? Certainly the old adage of sitting on your hands for 15 minutes is useful. Firstly though it is important to establish links with the interested parties and manage the site from an airline perspective. One thing for sure is, it will be a long drawn out process that does not require quick fixes or knee jerk reactions, but a well constructed and thought out process that will span several weeks or months but hopefully not years.

The basics of managing safety have not changed significantly from the first crash in 1908, to what we do today. Sure we gloss it up and use impressive acronyms, but the basics are the same. Safety is the identification, analysis, management and elimination, and/or mitigation to an acceptable level, of risks that threaten the capabilities of an organisation.

So how can we progress safety for the future? There are a number of initiatives in the workplace e.g. IOSA, SMS, ISAGO, Safety Plans, LOSA etc, all of which have good intentions. But how effective are they? That is the question that needs to be asked. What ever happened to the safety basics? Complicated processes can be confusing and can be less than helpful and even considered to be an excuse to carry out those safety basics.

Safety can be taken for granted and this is certainly true in some airlines. But if safety is genuinely the 'No.1 Priority,' then safety departments must be manned by the best qualified and motivated people, who receive suitable remuneration for their expertise. It should never be an area that is classified as 'the rocking chair of the airline', where good servants are hired for a couple of years past retirement age to top up their pensions.

It can be argued, to become an effective Safety Manager one needs an all round knowledge of aircraft and the airline operation. I agree, but safety must be an area where energetic thinkers and analysts are encouraged to join for a career, not as a stopgap for better things, or a retirement home for aging employees.

For me, safety management is not about fighting fires, but more about stopping the fires starting.

# Fighting the War on Maintenance Error

by Squadron Leader John Franklin MBE RAF DASC SO2 Eng FW

**With the current high levels of operational tempo and the rapid changes in the way engineering support is provided, more and more is being expected of our aircraft technicians. With constant pressure on maintenance personnel to achieve operational and training imperatives, there is a very real chance that maintenance error will occur and this could lead to catastrophic accidents if not identified and managed.**

Here at the DASC we are evolving our Human Factors programmes further to better understand maintenance error. Work has commenced to formally establish a Maintenance Error Management System (MEMS) across the MOD. A key part of any MEMS is the Maintenance Event Decision Aid (MEDA), which provides a comprehensive approach for conducting thorough and consistent investigations, determining the factors that lead to an error and making suggested improvements to reduce the likelihood of future errors. With the work in its infancy, it is important that in the meantime all personnel involved in aircraft maintenance appreciate that the first step in fighting the war on maintenance error is to understand what error is; only then, will we be able to effectively develop and implement such a system.

## What is Maintenance Error?

Humans make errors[1] frequently. In fact, humans make an error on average every 60 seconds. These errors can be as simple as typing the wrong letter in a word, or as serious as driving through a red light. In an aircraft maintenance context, maintenance error is a discrete form of human error. A maintenance error is the failure of the maintenance system (including the people involved) to perform in the manner we expect it to. It is different from a violation as the latter involves a deliberate departure from established rules and regulations.

## Common Maintenance Errors

Before we consider some of the principles of maintenance error management, it might first be useful to consider some of the most common maintenance errors that are seen here at DASC, from the incidents reports received from across all 3 services.

- Incorrect installation of components during maintenance.
- The fitting of wrong parts, such as bolts, washers and seals of incorrect size.
- Electrical wiring discrepancies, such as cross connections.
- Loose articles left in aircraft.
- Inadequate lubrication.
- Cowlings, access panels and fairings not secured.
- Fuel/oil caps not secured.
- Undercarriage ground locking pins not removed before flight.
- Contamination of systems.
- Aircraft damaged during moves, by vehicles or during functional testing.

*Figure 1 – Tornado ground damage.*

## Maintenance Error Management Principles

There are a number of measures that can be put in place in a maintenance system in order to catch a maintenance error before it becomes a problem during the flight of an aircraft. However, in order for these measures to be effectively implemented, the following principles of error management must be understood.

## Human Error is both Universal and Inevitable

Humans are not machines, so while the consequences of human error may be undesirable, it is important to understand that human error is as much a part of life as eating, sleeping and breathing. We are always at risk from human error and although it will never be completely eliminated, we must understand its effects in order to control the risk they pose.

## Errors are not intrinsically bad

Error is one of the fundamental drivers of human learning. Without committing errors we would be unlikely to learn or acquire all of the skills required for safe and efficient work. The key is to ensure that lessons are learnt and importantly shared as widely as possible to minimise the chance of someone making the same mistake.

*Figure 2 - KC135 over pressurisation during maintenance.*

## You cannot change the human condition, but you can change the conditions in which humans work

The problem with most errors is not that they have been committed, but that they have been committed in a safety-critical environment. Therefore it is important to recognise that we are operating in such an environment, recognise the error traps within the way we do business and base the way we approach the prevention of maintenance error around this understanding.

## The best people can make the worst errors

Errors are not just committed by inept individuals in the workplace. We must understand that all humans are capable of making errors and that even the best technicians are capable of making the worst mistakes.

## People cannot easily avoid those actions they did not intend to commit

Blame and punishment do not make much sense when the act that was committed was unintentional. This is the cornerstone of a just culture. This is not to say that people who have made an error should not be culpable for their actions; however punishment and blame will not stop error from recurring.

### Errors are consequences rather than causes

In the past, investigation techniques involved finding out who committed the error and then punishing that person as a warning and to try and stop others making the same mistake. However, it is better to see errors as consequences rather than causes, in that every error has a history and a chain of events that has led to the eventual outcome. Determining the factors that contributed to the error, and removing one of these factors from the error chain is far more beneficial.

### Maintenance error is about managing the manageable

We cannot control the uncontrollable. That is to say that there are certain human characteristics, such as being prone to distraction, forgetfulness and preoccupation, which although difficult to control, can be managed through training and experience. Situations and people cannot be controlled but they can be managed.

### Managing Maintenance Error

There are a number of measures that we currently have in place to prevent maintenance errors occurring. These include training, authorisations, supervision, inspection, quality audits, procedures, publications, rules and regulations. However, despite the many checks and balances in the system, maintenance errors still occur and a significant proportion of incident reports are put down as Human Factors (Non-Aircrew). Our understanding of these events could be better and we could certainly do more in the way we investigate and learn from maintenance error. This is one of the key purposes of the proposed introduction of MEMS and MEDA to the military air environment.

As a first step, management techniques within any maintenance organisation must identify those behaviours that are inappropriate and undesirable. These behaviours include poorly documented maintenance, failing to use or follow approved maintenance procedures, high operational tempo, perceived pressure, and a perception that we work in a blame free culture where personnel can deliberately commit violations without fear of retribution.

These must be replaced with appropriate behaviours that ensure maintenance personnel work within recognised risk boundaries using the established maintenance regulatory framework at all times, regardless of the external pressures. This is especially relevant on operations, where the temptation may exist to cut corners for perceived operational reasons.

If the system is wrong, it should be changed to ensure that it is right for others in the future. However, when doing so, we must be aware that what might be perceived to be the right way to do something at the individual or squadron level might not be considered correct at higher levels of the organisation. To that end, it is vital that changes are staffed appropriately before they are implemented. A consequence of this is that personnel in the command chain must ensure that suggested changes are actioned, one way or the other, as quickly as possible. A local work-around can only survive for so long before it results in an incident. At all stages any change process must be clearly understood by all involved in it, regardless of their position in the chain of command.

All maintenance incidents and near misses should be reported and investigated with the aim of identifying and eliminating error-promoting conditions. An example of the kind of error-promoting conditions that regularly pop up during Flight Safety occurrences are summarised by the 'Dirty Dozen'.

| Lack of: | Abundance of: |
|---|---|
| Communication | Pressure |
| Resources | Stress |
| Assertiveness | Norms |
| Awareness | Fatigue |
| Teamwork | Distraction |
| Knowledge | Complacency |

When it comes to investigating and reporting technical faults and errors, the focus should not necessarily be on what has been done to the aircraft to return it to a serviceable condition; this is the purpose of the maintenance documents. It is more useful to understand WHY the event occurred and what can be done to prevent it happening again. In Aviation Safety, there are rarely new errors – just old ones waiting for new people to make them, so the wider lessons must be publicised as widely as possible.

Maintenance error occurs because humans are at the heart of it. Its prevention relies on several quite simple measures: a just culture is vital to ensure that unintentional errors are not punished. Investigation of the chain of events leading to the error with the aim of determining all the contributing factors, and enabling maintenance managers to develop defences that will stop that event chain from occurring again. In this way we can ensure that our skillful technicians are given every assistance to enable them to deliver a safe and airworthy product to our flight crews.

Note

[1] An error is the failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention.

# Communication Error

by Ross James MacDonald, ATC Watch Manager – Gatwick Airport

**Aviate, navigate, and then communicate. It's an old adage that we've most likely all heard before, whether as pilots or controllers. However, simply because communicate comes in last doesn't make it any less of a critical part of the safety systems we build into the operation.**

"It's important to de-stress away from work, you know"

I was at the Isle of Wight Festival recently, something I would thoroughly recommend (you're never too old for live music). Whilst dancing away to 'Scouting for Girls' I decided to share the experience with a girl I'd been seeing. The message read something along the lines of:

'Dancing away to scouting for girls! What fun! X'.

Within 5 minutes the response was not favourable:

'I don't think that was meant for me.'

No kiss; always a bad sign.

'Read it again, it's the name of the band! X',

I sent, quickly trying to recover the situation.

'Oh... Sorry. Xx'.

Relationship normal, crisis averted; all but for the slightly hasty reading of a text and perhaps the skipping of the word 'to'...

Why share that with you? In my (so far) short time as an operational air traffic controller and supervisor at a major UK airport I've already encountered, investigated and indeed been involved in many incidents involving seemingly innocuous communication errors. If not always the direct cause of a problem they often aggravate a situation and increase the seriousness of an incident.

"We have a problem with the left phalange"

A serious event that occurred in London airspace has highlighted this issue, and even led to parliamentary debate on the subject (they didn't talk about my relationship mishaps however). An eastern European airline Boeing 737 outbound from London Heathrow suffered a navigation systems failure, and found itself tracking all over our skies. Why? Not as much to do with the navigation error as you may think. The communication between the pilot and ATC suffered numerous problems, partly because the pilots' English was not good and they struggled to explain the problem they had.

So what's the solution? Well, requirements for language proficiency are in the pipeline. Many states have committed to dates to ensure that their pilots and controllers are up to the International Civil Aviation Organisation's minimum 'level 4' proficiency. However, I've witnessed personally incidents between 'level 6' pilots and controllers, where confusion has prevailed!

Standard phraseology helps us out in these situations - and I'd encourage us all to use it where possible. It may be interesting to ask the pilots among you the last time you were tested in any way on what constitutes a 'standard phrase'; or where to find information on it? A group of NATS controllers and pilots recently undertook the task of producing a multiple-choice test for pilots and it may well be coming to a line check near you soon. Of course, you can always have a read of the CAP413 - the Radiotelephony Manual to refresh your memory.

"Handover on an Andover over Dover, over"

In recent times many changes have taken place in the UK's standard phrases - are you aware of them? It became clear a few years ago that the use of 'Flight Level One Zero Zero' and 'Flight Level One One Zero' was causing many level busts. This led to the UK introduction of 'Flight Level One Hundred' which has led to remarkable improvements.

In the more distant past the introduction of 'Pass your message' to replace 'Go ahead' was taken to prevent crews (and aerodrome drivers) from believing that their request had been approved. 'Recleared' is not used in the UK, rather 'Climb' and 'Descend' are preferred in all circumstances to act as a check when a pilot may misinterpret a call not directed at them.

More recently, and probably more widely-known, changes have been introduced to UK ILS phraseology, where 'Cleared for ILS approach' is not deemed to be appropriate. It was felt that pilots should be asked to 'report established' on the localiser and further to 'descend on the ILS'. This stems from numerous incidents of aircraft descending below minimum safe altitudes believing it was safe to do so. Controllers working in a busy environments will understand the need for flexibility in when they can use the RTF and hence even more recently pilots may be passed the instruction 'when established on the localiser, descend on the ILS...'.

One UK exception that I can relate to as a tower controller at a busy airport, is the UK difference regarding conditional line-up clearances. Almost all pilots will have received the instruction 'after the landing, line up' in the UK and 'behind the landing, line up behind' abroad; but why this obvious difference at such a critical phase of flight? It's a subtle difference, but it's felt that 'after' much more clearly indicates a sequential following in the departure order than 'behind', which could simply mean further back than the subject aircraft of the condition. Finally, consider an airport with left and right runway designators and the possible interpretation of 'behind the landing aircraft, line up runway ## right behind'...!

'After the sixth aircraft on the left that looks like all the others..."

Runway incursions and conditional clearances are subjects that I must consider every day at work. Using a runway to its capacity requires us to control the RTF so we can issue the instructions as soon as we need to, and pass information that allows pilots to decrease their response times as much as is practical. To both these ends conditional clearances are vital tools in our box. However, there is no doubt that from a human factors point of view, they can result in miscommunication.

So how can we minimise the risk of conditional clearances? Well controllers can be sensible about how they use them. I was informed by a pilot colleague (a training captain!) recently that 'If you tell me about something that's going to happen in more than 30 seconds time, I'm not interested, and will most likely forget". Now I'm no expert on the human factors side of this but it makes some sense. Our short-term memories are vulnerable (seven items, plus or minus two depending on the person, I'm led to believe), and controllers should be aware of other pilot's activities at this critical stage of flight. Do we really need to pass that conditional line up clearance on the aircraft at five miles now? Or do we need to have a series of four, five, six or even more aircraft committed to the runway through the use of conditionals?

"Did he just say what I thought he said?"

Pilots of course can play their part. A full read-back, including callsign, means that the risk of a miscommunication is reduced dramatically. Can you honestly say you use your callsign with every transmission? How many times have you heard something on the RTF and thought, that doesn't sound right? How many times have you read back a clearance only to be told it was something else and you hadn't realised?

Expectation bias - where you hear what you expect to hear, rather than what was actually said, is a frequent factor in reported incidents. A colleague of mine, when asked, told an aircraft that he was number two for departure. Having then changed his mind a few minutes later, he was surprised to see two aircraft line upon the runway - the aircraft he'd instructed to and the aircraft that, having also read back the clearance but been 'drowned out', believed that it was his turn.

The opportunity for error will always exist, but even on busy frequencies we can all act as a check for each other. I for one know that I will never be put out by having to say something twice if you're not sure of what I said; or if you think I haven't noticed an incorrect read-back from another crew. Finally, if you happen to be unfortunate enough to be a prospective girlfriend of mine, please read your messages carefully before responding.

# Clear-air turbulence and the sub-tropical jet streams

by Jim Galvin World Area Forecast Centre Forecaster

**Does significant clear-air turbulence occur in the tropics? When I first came into forecasting, the general view was that is was extremely rare, even though the strongest winds at the outer edges of the upper tropical troposphere – the sub-tropical jet streams – reach 230 kn or more at times.**

Turbulence occurs in the atmosphere as a result of the overturning of pockets of air. Much is associated with cloud, in particular at lower levels, but in the upper atmosphere, it often occurs in clear air, usually in small areas or pockets close to the bands of strong winds – the jet streams, where wind speed and direction change rapidly. Most turbulence at high levels is light, but forecasts often indicate areas where turbulence may be locally moderate or severe (Figure 1).

The sub-tropical jet streams (STJs) are generally westerly winds that mark the edge of the tropics. The core of these winds is near FL390 and is usually found close to 30 oN and 30 oS (Figure 2). In places, the jet stream may have considerable depth (more than 30,000 ft) and a horizontal extent of more than 10 o latitude. Speeds are highest in winter and may be absent in summer, in particular in the northern hemisphere, when its speed is rarely more than 80 kn, except across the Pacific Ocean. When there is a strong interaction of cold and warm air, the speed of the STJ reaches a peak, usually in spring and autumn.

## Folds and bifurcations in the STJ

Most waves in the STJ have only small amplitude and a long wavelength, which is one of the reasons to believe that there is generally little turbulence associated with them. However, the situation over the eastern Pacific Ocean, where the warmest air is usually confined to a narrow band near the equator, frequently causes the STJ to split into two widely-separated streams. This development is most marked in the winter.

When this bifurcation occurs, one stream is found close to 15 oN or 15 oS, its core around FL420 and the other (faster) stream near 40 oN and 35 oS, its core around FL370. Where the flow splits, a tight Z-shaped fold forms in the northern-hemisphere flow. It is S-shaped in the southern-hemisphere. These folds are found close to the 180th meridian. Although this is the most common area for folds to form in the STJ, they sometimes occur elsewhere.

Over land in particular, where large troughs develop in the STJ, the cooler air aloft can enhance deep convection, as the poleward side of the jet stream is brought unusually close to the equator, over warm moist air close to the surface.

## Clear-air turbulence

Although the flow of the STJ is relatively modest in the contorted flow close to the equator (usually no more than 100 kn), there is often considerable deceleration of the flow into the fold, associated with curvature and divergence – a measure of the rate at which air is spreading away from the centre of the flow, as well as convergence – a measure of the rate at which air is moving into the centre of the flow – into the equatorward branch1. (This is particularly true in the northern hemisphere, where the strongest flow of the STJ is usually found close to Japan.) The result can be moderate (occasionally severe) turbulence (Figure 3), which almost always occurs in clear air. This was a particularly notable cause in investigations by Turner and Bysouth2. Close to the equator, the STJ is also only in weak balance with the forces that drive it, so small-scale confluent and diffluent flow may be expected, resulting in overturning and local pockets of light to moderate clear-air turbulence (CAT).

CAT may affect flights at high levels and is a major cause of discomfort and disruption to passengers in flight. It is relatively rare in the tropics, but does occur at times in association with the STJ3. Table 1 shows the percentage probabilities of a flight encountering turbulence for every 100 km of flight within the tropics. It is usually accepted that moderate, or occasionally severe turbulence should be forecast where the indicated probability of CAT is greater than about 6% per 100 km of flight5.

Given the high altitude of the STJ, air density is relatively low, so the effects of acceleration and deceleration are relatively modest6. CAT is most likely close to the core of the jet stream and below it, on the cold (normally poleward) side.

As the component of the flow in the STJ that does not follow altitude contours is generally small and accelerations are usually gradual, its flow is not generally turbulent. However, the temperature difference between tropical and that of the extra-tropics is often large in winter, resulting in a large horizontal wind shear on the poleward edge of the flow. In these conditions, especially where there is anticyclonic curvature and the STJ speed is high, moderate turbulence may occur7 This is almost always in clear air, since the STJ is only associated with weather systems in limited areas8.

Where the speed of the air flow changes rapidly, either vertically or horizontally, turbulence is usually the result. Where this occurs in clear air, it presents an invisible hazard to aircraft and it is essential that significant areas of CAT, despite their low probability in any one place, are indicated on forecast charts.

Various mathematical, semi-empirical rules have been devised to predict CAT. Wind-shear values of 20 kn per 100 km in the horizontal and 20 kn per 1000 ft in the vertical may be expected to produce pockets of moderate CAT. Values of 30 kn per 100 km in the horizontal and 30 kn per 1000 ft in the vertical may produce pockets of severe CAT6.

## Interaction with mountain ranges

The depth of the flow of the STJ tends to bring its lower part into contact with several mountain ranges, notably the Andes in the southern hemisphere; the Rockies and the Himalayan complex in the northern hemisphere. This interaction generates CAT close to the level of the peaks, in particular those aligned across the flow. The highest mountains that lie across the flow of the STJ in winter is the Hengduan Shan of southern China, which reaches more than 16,000 ft and the Andes of South America, which reach around 17,000 ft. Turbulence is very likely to occur to the east of these ranges, especially as there is a generally easterly flow below the level of the mountain tops, against that of the STJ9. In spring and autumn, the highest ranges of the Himalaya also interact with the STJ, as it makes its way, respectively, north and south. At this time of year, speeds are usually high (typically reaching 130 kn to 150 kn). This turbulence, which may be within cloud during the winter monsoon season, may be considered a serious hazard to aircraft flying at medium levels. Where large-scale atmospheric waves are generated by the stable flow over these mountains, moderate turbulence may occur throughout the troposphere and into the lower stratosphere.

Associated with the STJ, but separate from it, further areas of tropical CAT are also observed at times. These may be identified by their high-cloud signature, as in many cases they occur where wind speeds are not above 80 kn. Ribbons of cirrus may be seen and may persist for days within areas where there is a large horizontal wind shear (Figure 4). This often occurs within upper troughs previously associated with a cold front, the deep cloud of which has dissolved. These have been noted, in particular, over the Arabian Sea, close to the wintertime trough in the STJ.

## Other causes of turbulence

Although forecasters are most interested in forecasting CAT, there are two other areas that cause significant turbulence at medium and upper levels. Most important are areas of cumulonimbus and cumulus clouds, where vertical velocities are often very high – both up and down. Layer clouds also cause light to moderate turbulence, but they can be seen and turbulence can normally be expected within them.

The strength and local distortion of the STJ, as well as its interaction with the high mountain ranges at the tropical margins, generate areas of CAT, locally moderate in strength. Over the eastern Pacific, turbulence may occur surprisingly close to the equator.

## Forecasts of clear-air turbulence

Currently the main source of CAT forecasts is SIGMETS (for severe turbulence) and SigWx charts, most of the latter issued by the World Area Forecast Centres in London and Kansas City (see Fig. 1). However, as many of the factors that generate CAT are represented by numerical prediction models of the atmosphere2, the Met Office has been conducting a trial, issuing numerical GRIB10 files direct from its weather-prediction model, showing areas of CAT probability5. Pilots can expect to use these CAT fields more and more in coming years, as they are expected to be considered operational within two years or so.

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2) Turner, J. A. and Bysouth, C. E. (1999) Automated systems for predicting clear air turbulence in global aviation forecasts. Proc. 8th Conf. Aviation, Range Aerosp. Meteorol., Dallas, Texas. American Meteorological Society, pp 368-372

3) Roach, W. T. and Bysouth, C. E. (2002) How often does severe clear air turbulence occur over tropical oceans? Weather, **57**, pp 8-19

4) Atkinson, G. D. (1971) Forecasters' guide to tropical meteorology. University Press of the Pacific, Honolulu (2002 reprint)

5) The Met Office issues ICAO GRIB bulletins for 36 hours at 6-hour intervals, showing areas of potential CAT development (on an experimental basis) from model runs at 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC.

6) Meteorological Office (1994) Handbook of aviation meteorology. 3rd edition. HMSO Press, London

7) Asnani, G. C. (1993) Tropical meteorology (2 vols.). G. C. Asnani, Pune

8) Where the STJ forms troughs, due to the equatorward advance of cold air, semi-permanent lines of cloud, similar to high-latitude fronts, but containing isolated or occasional embedded cumulonimbus clouds may be found. These are most often seen over the south-west Atlantic Ocean, central south Pacific Ocean, south-west Indian Ocean and north-west Atlantic Ocean (see Figure 1).

9) Galvin, J. F. P. and Walker, J. M. (2007) Weather image. Cloudy South-East Asia. Weather, 62, pp. 55-56

10) Gridded Binary data, of a format similar to that of the winds and temperatures used for flight planning

Table 1. Percent frequency of CAT within the tropics per 100 km flight [4]

| Area | Turbulance category | | | | No. of Observations |
|---|---|---|---|---|---|
| | None | Light | Moderate | Serve | |
| **0° – 30° N** | 91.3% | 6.0% | 2.7% | 0.1% | 12,619 |
| **Indian Ocean (0° – 15° S)** | 96.0% | 2.7% | 1.3% | 0.0% | 149 |
| **Africa (south of 15° N)** | 94.8% | 3.7% | 1.4% | 0.1% | 4,258 |
| **All zones** | 91.9% | 5.5% | 2.5% | 0.1% | 17,006 |

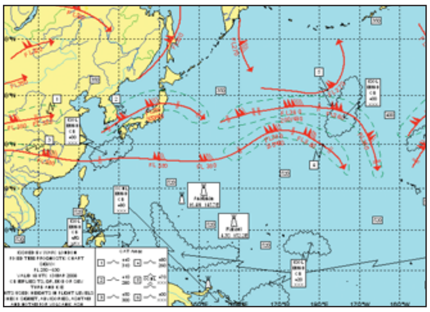

*Figure 1. ICAO 24-hour high-level SigWx forecast produced by WAFC, London, valid 1800 UTC on 13 March 2008, extracted from the transmitted BUFR data set. Areas of probable CAT, in particular area 4, associated with the STJ over the Pacific Ocean are shown within zones enclosed by green dashes. The depth of the CAT fields appears in the "CAT areas" box (bottom left).*

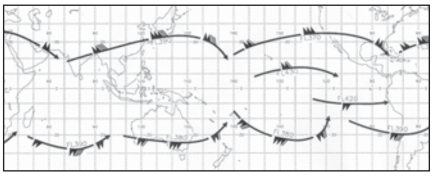

*Figure 2. Typical wintertime flow of the STJ (both hemispheres). The core of the flow is shown with altitudes in hundreds of feet (International Standard Atmosphere) given opposite the fleches. Fleches show 50 kn as triangles and 10 kn as bars with the head and tail of the flow at 80 kn.*

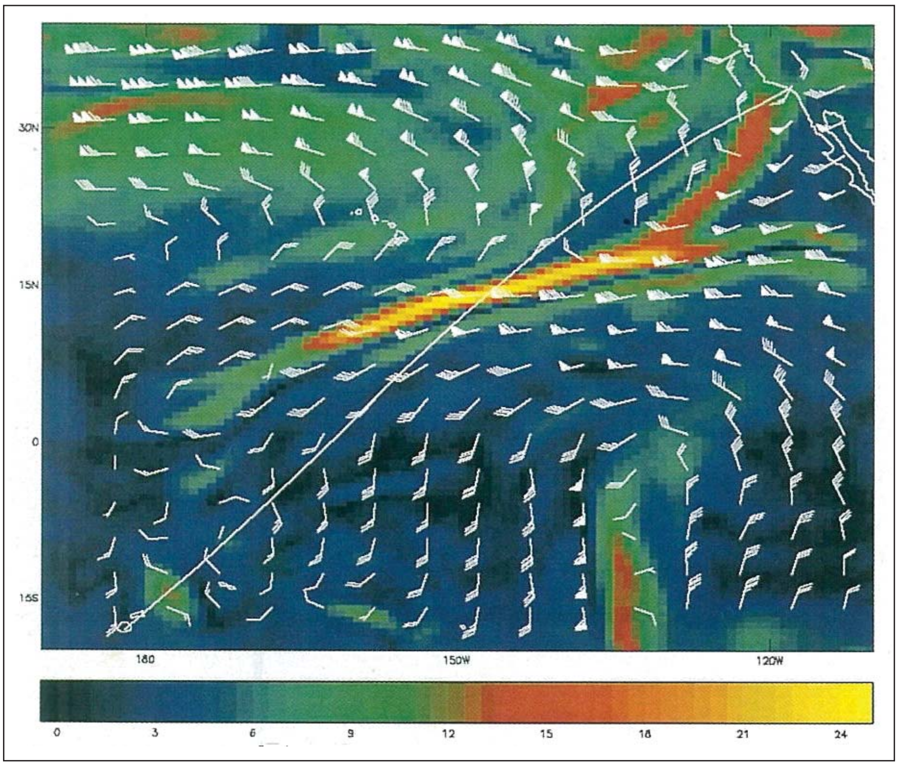


*Figure 3*

*Figure 3. Wind speed and direction at 200 hPa (FL390) and values of Brown's indicator of clear-air turbulence (10-5 s-1) over the eastern equatorial Pacific at 1800 UTC on 24 February 19991. The white line indicates the path of a flight from Fiji to Los Angeles which encountered turbulence for much of the journey on that day. It may be a surprise to see the greatest probability of CAT associated with a jet stream of only 110 kn, when the STJ upstream (near the 180th meridian) has a peak speed near 170 kn, but no more than moderate turbulence. [Note: this indicator has the dimensions of wind shear (s-1) and is a numerical measure of severity, as well as risk, whereas no measure severity is provided by the probabilistic indicator produced as GRIB files. [In very broad terms, 3 x 10-5 s-1 » 1 % 100 km-1.]*

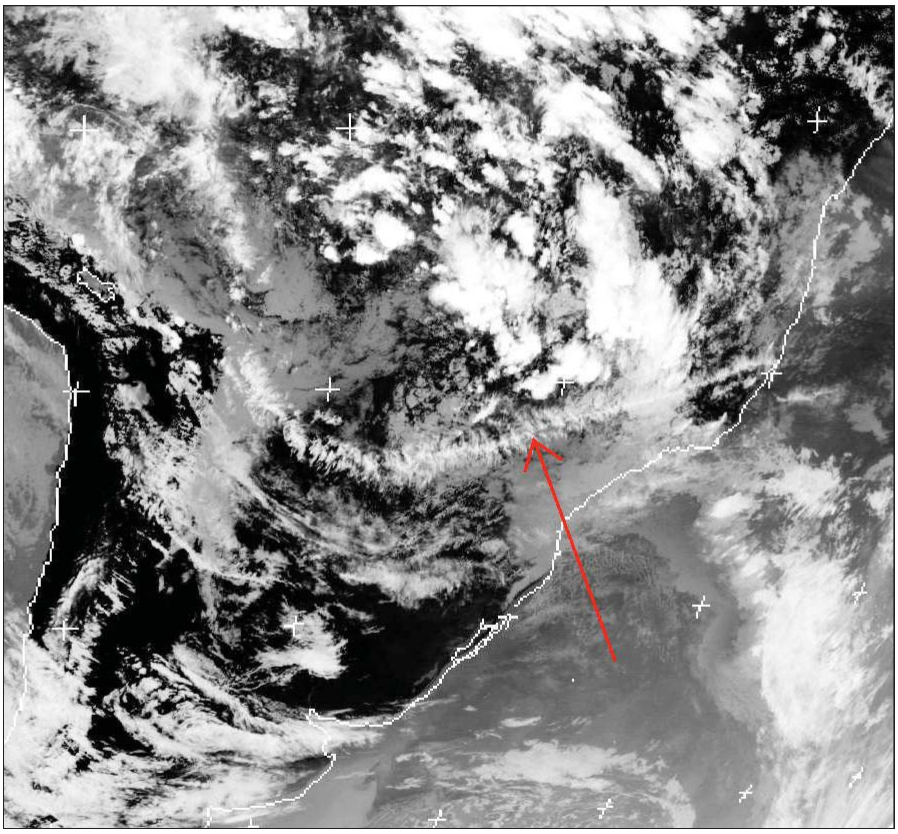

*Figure 4*

*Figure 4. Satellite image of ribbons of cirriform cloud associated with wind shear over South America at 1800 UTC on 17 October 2006. (Courtesy NOAA/NESDIS)*

# The Operation & Interpretation of Weather Radar

Ratan Khatwa PhD FRAeS, Honeywell Aerospace, Seattle, USA

## Summary

**This article presents a study that identifies and analyses factors that are associated with the operational use of weather radar by flights crews. The investigation included three main activities: a human factors evaluation to gain a better understanding of how flight crews operate weather radar; a survey of flight crew designed to assess their understanding of weather radar fundamentals and perceptions of current day training; and an analysis of incidents/accidents involving the use of weather radar. The data revealed some shortcomings in the understanding of fundamental concepts in the operation of weather radar and that dedicated crew training for weather radar does not appear to be standard practice. Areas for improvements in training are covered. In addition, the role of new technology to improve pilot's weather awareness and decision-making are briefly described.**

## 1. Introduction

The primary function of airborne weather radar is weather analysis and avoidance. It is therefore not a "weather penetration tool". However, the proper operation and interpretation of airborne weather radar is dependent upon pilots having an adequate understanding of its capabilities, the provision of dedicated crew training and appropriate standard operating procedures. During the development of Honeywell's next generation weather radar family, IntuVue™, part of the design strategy was to establish a clear understanding of how current generation weather radar is used by flight crews and to identify areas of difficulty and concerns of line pilots. A primary design goal for the various models within the IntuVue family was to simplify the crew's task of system operation. An important number of findings related to the operational use of conventional weather radar were uncovered during subsequent human factors investigations.

Those areas of the investigation are the focus of the current article, namely:

- Flight crew perception of current weather radar training.
- Flight crew knowledge of weather radar fundamentals.
- The role of weather radar operation in accidents/incidents.

The techniques used to scrutinize these areas included:

- Survey of flight crews around the world.
- Human factors evaluations involving pilots using weather radar.
- Analysis of incidents/accidents where the flight crew operation of conventional weather radar was included in the investigation.

This article is limited to the role of flight crews using weather radar. There are always multiple factors associated with operational safety and the cause of accidents. The data presented herein should be viewed with a balanced perspective. The safety information and recommendations herein are not intended to supersede any policies, practices or requirements.

## 2. Flight Crew Weather Radar Survey

Forty-six ATP-rated pilots participated in a survey conducted to gain insight into pilot knowledge of conventional weather radar principles and their views on current weather radar training. The group comprised a culturally diverse population from North America, Europe and Asia. Most participants were airline pilots although some corporate operators participated. Pilot experience varied from 3,200 – 35,000 hours total time and average age was 52. All pilots were experienced in using weather radar. A summary of survey data is presented below.

1) Eighty-five percent of the pilots understood the antenna stabilization concept. Antenna stabilization maintains a constant angle between the weather radar antenna and the target area being scanned, regardless of variations in aircraft pitch and/or roll attitude.

2)Sixty-three percent of pilots did not appreciate that tilt angle needs to be managed to compensate for Earth curvature effects. The effect of the Earth's curvature becomes noticeable at ranges above 40 mi, and if ignored can lead to weather image interpretation errors. The effect becomes very significant as range increases.

3) Fifty-five percent of pilots were unaware that a weather target partially within a radar beam may not be presented at its "true color" on the weather display. The color selected for display is a direct function of the power returned to the receiver. In cases where the beam is partially filled, the total power returned (averaged over the beam) may not represent the calibrated value associated with the target cell.

4) Sixty-three percent of pilots were unaware that at cruise altitudes of FL > 310, green radar echoes at short range near the current Flight Level should be avoided. Typically at these altitudes, the targets are less reflective. At high altitudes there is a possibility of the presence of unstable air and hail above the storm cell. It is therefore not advisable to penetrate the less reflective part of the storm top. This factor was also identified in the accident/incident analysis and the pilot-in-the-loop evaluation described later in this article.

5) Seventy-three percent of pilots were aware that tilt angle does not need to match a climb, or descent, angle to detect weather on the flight path. The antenna should be pointed at the base of the convective weather cell during climb. Generally, the lower 18,000 feet is the most reflective part of the storm. Radar should be used to analyze the weather characteristics such as the vertical extent of cells and avoid strong convective activity. Returns along the flight path angle may not necessarily provide a full indication of storm intensity and turbulence levels encountered if penetrating the cell.

6) Eighty-eight percent of pilots were unaware of the range at which their radar is no longer calibrated and returns are displayed at their true levels. Radar beams broaden with distance, thus decreasing the proportion of the beam which is filled with moisture. At shorter ranges, the returned power is more representative of the target cell and therefore it is more likely to be displayed at its true calibrated value. Typically, weather radar returns are calibrated within a range of up to 60-80 mi.

7) Sixty-eight percent of pilots felt that their current weather radar training is insufficient. Examples of specific pilot comments include the following:

- "Equipment specification and limitations not well understood. Line training standards variable with few or ill-defined standards".
- "Imprecise knowledge of the system – vague guidelines about what to do with information presented".
- "Insufficient information about interpreting radar display and use of tilt".
- "Mostly taught by on-the-job training, so myths and wrong concepts easily passed on".
- "We learn by using weather radar out in the real world. Training is practically non-existent".

## 3. Pilot-in-the-Loop Evaluation

As stated earlier, part of the design strategy for the IntuVue family of weather radars, and specifically the RDR-4000-the first model developed for Air Transport platforms-was to establish a clear understanding of how conventional radars are used by flight crews and to identify areas of difficulty and concerns of pilots. A comparative evaluation was performed that involved independent groups of pilots using the new RDR-4000 radar display modes and conventional weather radar. This study is described in detail elsewhere (see Ref. 1,2) and only those aspects relevant to conventional weather radar operation are discussed here. Thirteen pilots with an average total time of 12,423 hours experience participated in the evaluation with conventional radar. Average subject age was 54 years. Pilots were required to operate the weather radar in a wide range of operational scenarios using a PC-based part-task simulator. The primary task was to detect and avoid potential weather hazards. The weather detection and decision-making data are presented in Figure 1. A "correct decision" implies avoiding penetration of significant weather. In those cases where significant weather was penetrated, factors included mis-management of tilt, gain and range. Mis-management of tilt was the most frequent factor and examples include using only upward tilt or zero tilt, no change in tilt, and over scanning the most reflective part of the cell. In these cases the cell of interest was either not displayed or appeared to have green echoes and consequently subjects continued into the threat area. Also, in one scenario some subjects did not appreciate the significance of green radar echoes at high cruise altitudes at close range. In more than 80% of the cases pilots using conventional weather radar detected significant weather. Note that pilots using the RDR-4000 display modes exposed to identical scenarios actually performed significantly better in detecting and avoiding significant weather, e.g. detection rates better than 95%.

## 4. Analysis of Flight Crew Operation of Radar During Weather Encounters

The objective was to identify and analyze those factors related to the flight crew operation and interpretation of weather radar from reports of actual weather encounters.

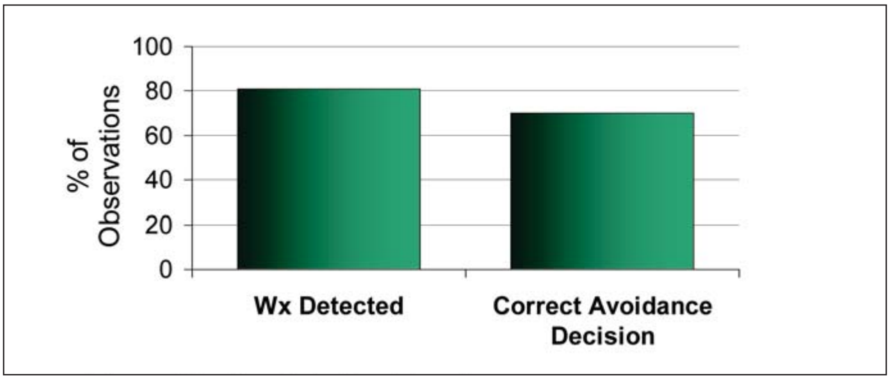


**Figure 1 Weather Detection & Avoidance**

Multiple factors are always involved in any aviation occurrence, and the limitation of this study is that it does not include many other critical factors such as provision of timely weather information, accuracy of weather data, role of ATC, regulator, etc.

An extensive review of formal occurrence reports from nine worldwide accident investigation bodies was conducted for the period 1987-2007. Sufficient data for fixed-wing aircraft engaged on public transport, business/corporate and freight operations involved in 14 occurrences were identified.

Unfortunately the role of weather radar operation was either not discussed, or insufficient information was included in most final investigation reports. Some highlights of the results are presented below.

One-quarter of the injuries were fatal and half the aircraft was either substantially damaged or destroyed. Many incidents included substantial hail damage, typically to windshields; nose radome; radar antenna; wing, horizontal stabilizer and vertical stabilizer leading edges; and engine inlet cowls. Half of the events occurred during cruise with 35% occurring between top-of-descent and the destination airfield. Figure 2 show the distribution of occurrences across flight phase.

More than half the cases occurred in Instrument Meteorological Conditions (IMC). Thunderstorms were present in all cases of severe weather penetration and more importantly this signifies the presence of cumulonimbus cloud formation. A cumulonimbus cloud entails a risk of moderate or severe turbulence, icing and hail as confirmed by the study data. Several of the occurrences involved multi-cellular storms or squall lines. In most cases, severe levels of turbulence prevailed.

Hail was present in almost two-thirds of the cases and lightning was present in approximately onethird of the sample.

### 4.1 Weather Radar Operations

Figure 3 shows that in almost two-thirds of the occurrences, the operation of the weather radar and/or interpretation of the radar display were not necessarily optimal. Specific examples include:

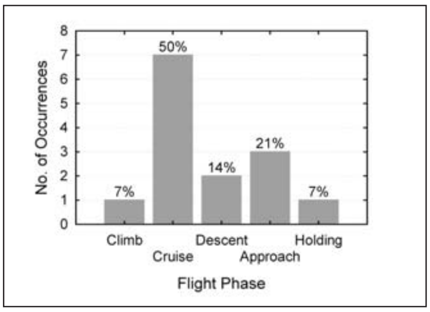


**Figure 2 Flight Phase Distribution**

- Improper tilt operation—such as over-scanning storm cells, maintaining a constant tilt and not actively managing tilt in areas forecasted with unstable/convective activity. Figure 4 shows that this occurred in at least 43% of the cases. To keep track of weather in the vicinity of the flight path, the antenna tilt angle should be periodically adjusted. As the altitude changes or as the aircraft gets closer to the storm cell, tilt angle needs to be changed so the radar beam keeps scanning the most reflective part of the storm. During over-scanning the centre of the radar beam scans above the most reflective part of the weather cells and hence significant returns may not be presented on the radar display: the actual thunderstorm top may still be in the aircraft flight path and inadvertent penetration of a storm top is possible.
- Improper use of gain control.
- Misinterpretation of ground returns (built-up city area) as significant weather.
- Weather radar in OFF position despite forecasted cumulonimbus formation.
- Not fully appreciating the limitations of the radar and impact on the displayed image (e.g., radar attenuation, absence of significant echoes (red/amber) at high cruise altitudes).

### 4.2 Radar Training and Operational Documentation

Figure 5 reveals that in at least half of all cases appropriate training for weather radar use was not provided to flight crews, examples include:

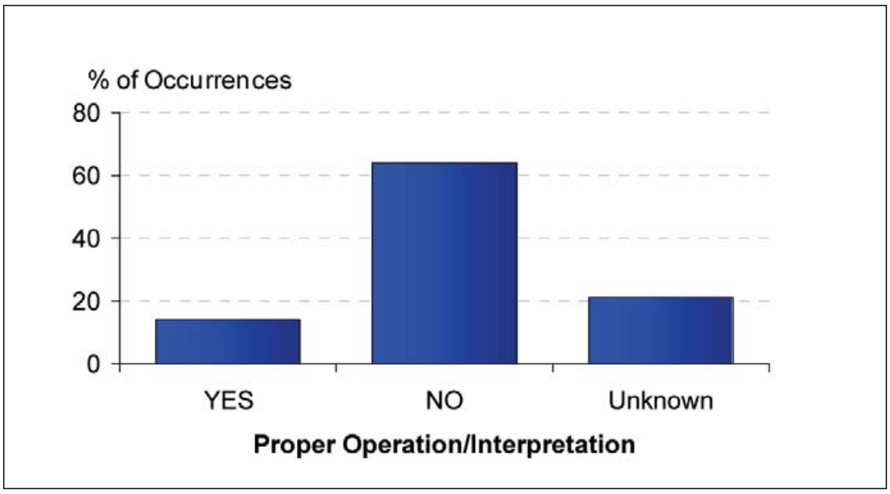


**Figure 3 Radar Operation & Display Interpretation**

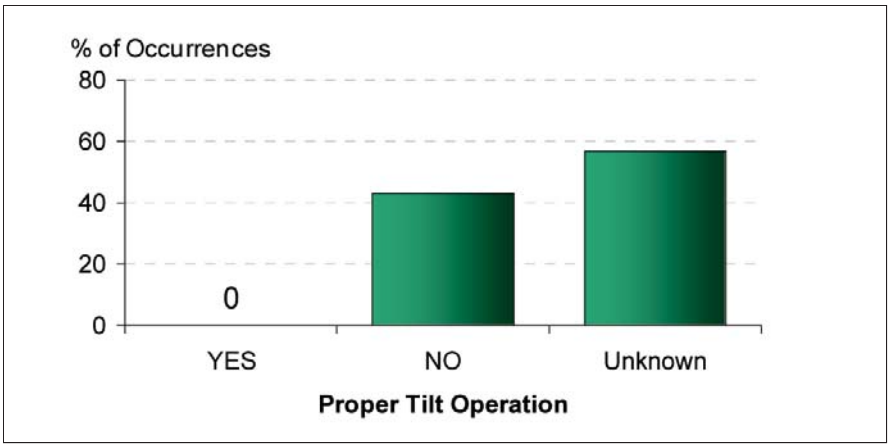


**Figure 3 Radar Operation & Display Interpretation**

Note that these findings correlate with pilot feedback in the survey presented in Section 2.

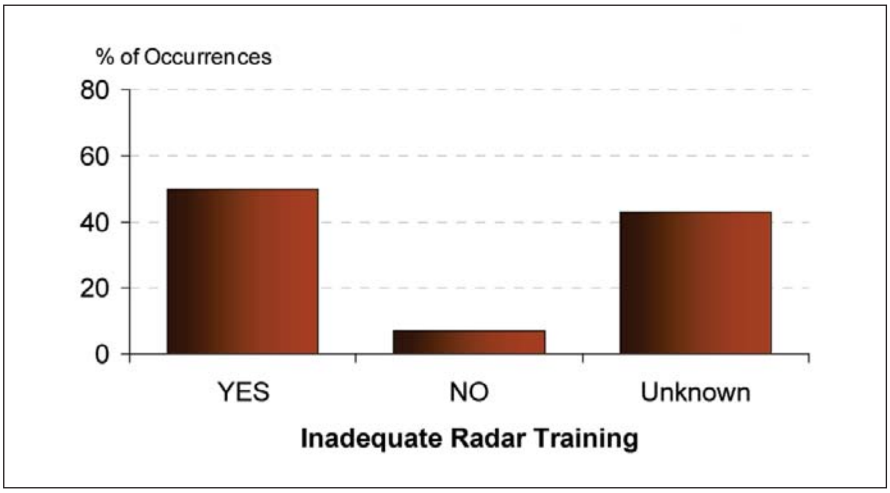


**Figure 5 Radar Training**

It should also be noted that in several instances inadequate operational documentation such as the Aircraft Operations Manual were cited by the investigation body:

- Pilots without any formal training on the use of radar. Instances were revealed where pilots indicated that their training was limited to *"trial and error experience and information from other pilots"* and *"learning by doing."* This approach can lead to improper radar operating procedures and techniques.
- Insufficient training standards/ requirements by company management not requiring weatherradar training in recurrent, upgrade and re-qualification training.
- The radar training provided did not adequately address the specific operating characteristics and procedures of the installed system.
- Pilot Guides furnished to the operator by the radar manufacturer that contained information on the operation of the radar, and detailed advice on weather detection and interpretation, were not used during training or made available to flight crews.
- No information on the operation of, or suggested techniques for use of, radar in day-to-day operation.
- Not sufficiently clear in its description of the recommended technique for operating the radar for weather avoidance.

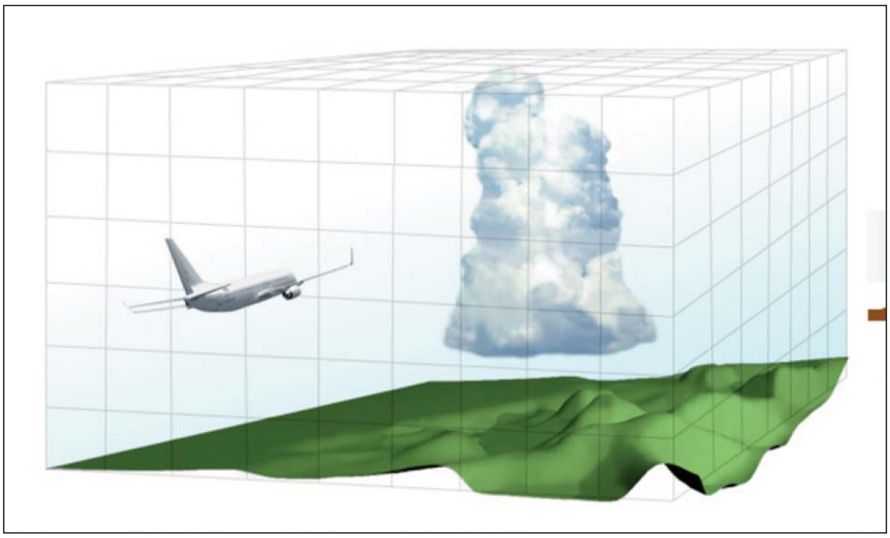

**Figure 6 IntuVue Volumetric Buffer**

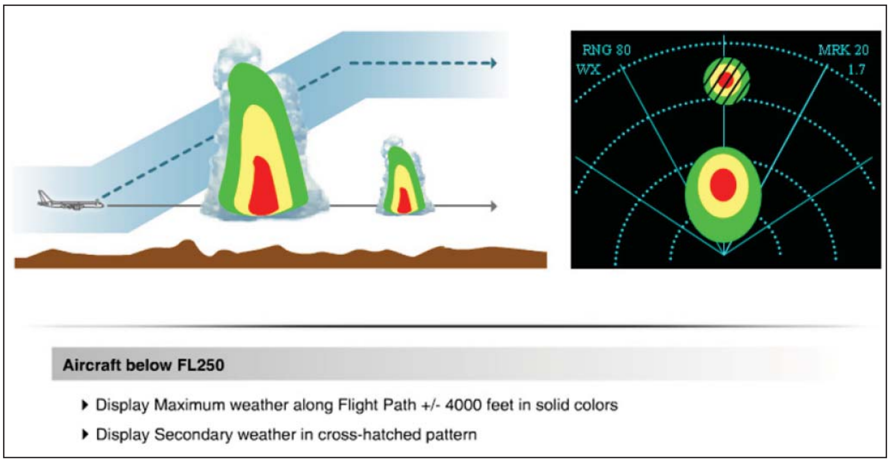


**Figure 7 RDR-4000 AUTO Mode Example**

## 5. Technology Improvements

The advent of technology improvements for commercial uses and the ability to store reflectivity data in real-time in a 3-deminsional volumetric buffer provide the opportunity of presenting weather information that is more *task-orientated* than has traditionally been the case. Honeywell's IntuVue 3-D weather radar has a range of 320 miles and supports elevations of up to 60,000 feet. The radar system continuously scans the entire three-dimensional space in front of the aircraft, and stores all reflectivity data in an earth-referenced three-dimensional ("volumetric") memory buffer. This buffer is continuously updated with reflectivity data from new scans. The reflectivity data are extracted from the buffer to generate the desired display views without having to make (and wait for) view-specific antenna scans.

Information requirements were central to addressing many of the challenges that face flight crews when using conventional weather radar:

- The tilt management task for the weather detection task has been eliminated – there is no tilt control for the RDR-4000 weather display modes.
- The weather information presented to the crew is automatically corrected for Earth curvature effects by the RDR-4000 system. Judicious tilt management and cognitive effort is therefore no longer required for interpreting weather returns at longer ranges.
- The display mode selection task has changed from allowing the flight crew to select a single "WX" mode to either a "MANUAL" or "AUTOMATIC" weather display mode.
- The AUTOMATIC mode enables strategic weather detection information. An automatic distinction is made between weather associated with the intended vertical flight path and weather that is not. In this mode, "Flight Path Weather", or weather near the altitude of the intended flight path, is displayed differently from "Secondary Weather", which is further away from the flight path. The separation is accomplished by applying an envelope around the intended flight path: weather within the

envelope is considered Flight Path Weather; weather outside the envelope is Secondary Weather. Secondary Weather is visually distinguished from Flight Path Weather by black stripes.

- The MANUAL (Constant Altitude) display mode presents constant altitude weather on a plan view display for storm cell analysis and tactical avoidance tasks. This eliminates cognitive processing associated with pilot's mental computation of cloud tops/bases. The crew is required to select an altitude of interest on the control panel. As mentioned above, the data is also corrected for the Earth's curvature.

- Terrain data is used to automatically reduce ground clutter in the weather display modes – the crew is not required to adjust controls in order to discriminate between weather and ground returns on the display.

- A vertical profile (side-view) display of weather is also available.

This system is in service on the Airbus 380, Boeing 777 and 737NG and C-17 platforms.

## 6. Recommendations

1) Operators should provide crews with formal initial and recurrent weather radar training. Fundamental concepts in the operation of weather radar (beam coverage, Earth curvature effects, antenna stabilization, tilt and gain management, calibrated weather and range) should be included. In addition, system limitations such as attenuation and significance of green radar echoes at high altitude should be included.

2) The significance of precision tilt management for detection, analyzing, and avoiding hazardous convective weather, and pitfalls of over-scanning storm cells should be emphasised during crew training.

3) The radar training program should include information on the specific radar that the flight crew will be using and should reference the information provided by the manufacturer concerning its limitations and recommended operating procedures.

4) Operators should provide guidelines relating to when, and if, radar should be selected OFF.

5) Operators should ensure that the Aircraft Operations Manual provides a clear description of the recommended techniques for operating the radar for weather avoidance.

6) Radar manufacturers should investigate the feasibility of developing radars that simplify both the system operation and interpretation of the weather display.

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*Rob Seaman*

# Air France Runway Overrun – TEM Analysis

by Peter Simpson, Manager Air Safety, Cathay Pacific

**The aim of analysing this incident using the Threat & Error Management (TEM) methodology is to enable crew to develop strategies to manage the threats and errors faced by this crew. It should be highlighted that TEM analysis does not cover organisational (latent) failures in much detail, rather it focuses on the aspects of the incident that crew have some level of control over. The organisational aspects are covered in the Transportation Safety Board of Canada investigation report, which is downloadable from their website at http://bst-tsb.gc.ca/en/reports/air/2005/a05h0002/a05h002.pdf**

## Introduction

Air France flight 358, an A340-300 aircraft departed Paris (CDG), France, at 1153 (UTC) on a scheduled flight to Toronto (YYZ), Ontario, with 297 passengers and 12 crew members on board.

Before departure, the crew obtained the arrival weather forecast, which noted the possibility of thunderstorms. While approaching Toronto, the crew were advised of weather-related delays. On final approach to RWY 24L, they were advised that the crew of an aircraft landing ahead of them had reported poor braking action, and Air France's weather radar was displaying heavy precipitation encroaching on the runway from the northwest. At about 200 feet above the runway threshold, while on the 24L ILS with autopilot and autothrust disconnected, the aircraft deviated above the glideslope and the groundspeed began to increase. The aircraft crossed the runway threshold about 40 feet above the glideslope.

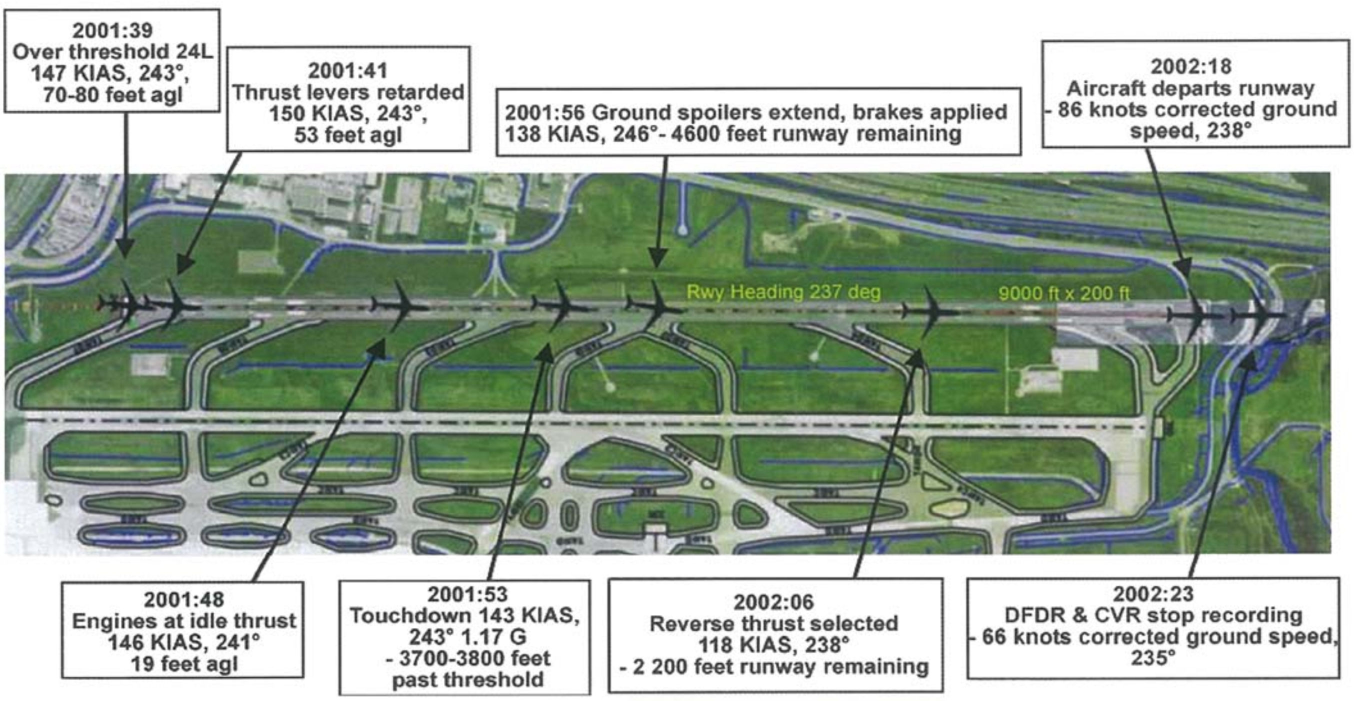
During the flare, the aircraft travelled through an area of heavy rain and visual contact with the runway environment was significantly reduced. There were numerous lightning strikes occurring, particularly at the end of the runway. The aircraft touched down about 3800 ft down the 9000 ft runway, reverse thrust was selected about 12.8 seconds after landing, and full reverse was selected 16.4 seconds after touchdown. The aircraft was not able to stop on the remaining 5200 ft and departed the far end at about 80 knots. The aircraft stopped in a ravine at 2002 UTC (1602 Local) and caught fire. All passengers and crew members were able to evacuate the aircraft before the fire reached the escape routes. A total of 2 crew members and 10 passengers were seriously injured during the crash and the ensuing evacuation.

The incident is analysed using a TEM framework. The Threats are listed, and then the threat recognition and threat management aspects are discussed. The same process is then applied to the Errors. The Undesired Aircraft States (UAS) are described, and finally the lesson learnt are discussed.

## Threats

During the cruise and initial descent, the crew displayed effective threat management strategies. However, as the approach continued, the threats were no longer being recognised, and those that were recognised were not effectively managed.

- **Weather.** Severe thunderstorms, heavy rain and hail, low visibility, lightning and changing winds.
- **Fuel Remaining.** Due to delays and holding, diversion fuel was almost exhausted.



- **Runway Conditions.** The runway was contaminated and braking reported as poor.
- **Runway Length.** The runway length left little margin for error.
- **Crosswind/Tailwind.** Around 1000 ft there was a strong crosswind. Below 300 ft the wind shifted with tailwind component of up to 10 kts,
- **Reduced visibility.** Forward visibility was lost in the flare due to rain.
- **Unstable/High Energy Approach.** At the threshold the aircraft was 40ft above glideslope and then landed deep.
- **High workload.** During the final phase of the approach and landing, the workload saturated the crew, who became fixated on landing.
- **Missed approach path** was obscured by thunderstorms.
- **Deep landing,** 3800 ft down the 9000 ft runway.

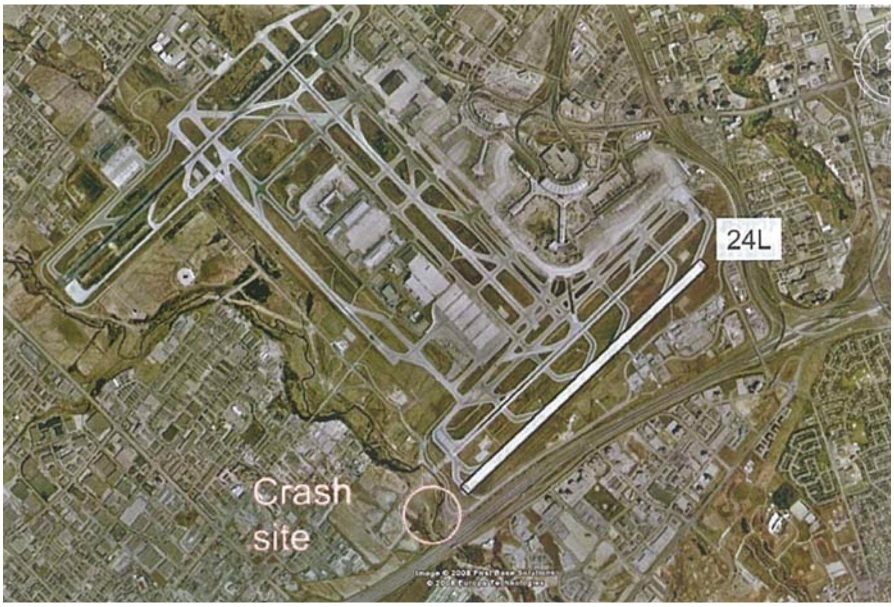
## Threat Recognition / Management

- **Weather**
  (enroute and arrival)
  **Recognised: yes**
  **Managed: yes**
  Forecast thunderstorm activity was the primary threat faced by the crew and they had uplifted an additional 3 tonnes of fuel, giving an extra 23mins of holding to manage this threat. Enroute the crew obtained regular weather updates for YYZ and alternates. It was only in the last hour of flight that the weather conditions rapidly deteriorated. In response to the first report of poor weather and lightning (just over 1 hour before landing), the crew reassessed diversion airports, and eventually changed their primary choice to Ottawa Airport (YOW) due to weather considerations. Ten minutes before landing the crew noted red weather radar returns along their approach path, and decided to continue the approach with caution. To manage the threat the crew reviewed the windshear recovery procedure and discussed the flight path for a (non-standard) missed approach, including which cells to manoeuvre between. At this stage the crew believed a missed approach was still an option. The PM was monitoring the winds and advising the PF.

- **Weather**
  (approach and landing)
  **Recognised: yes**
  **Managed: no**
  During final stages of approach, the crew had visual contact with the ground about 2-3nm from the runway. There was heavy lightning on both sides of the runway and red radar returns were showing at the end of the runway area. For a 5 minute period either side of the landing, the rain and hail had been recorded at 1.6mm/min (almost 100mm/hour, which is 50% higher than a Black Rainstorm Warning in HKG). The lightning activity was significant, with five ground strikes reported near the runway threshold in a several second period. After crossing the runway threshold the aircraft entered an area of heavy rain, with numerous lightning strikes and severely reduced visual contact with the ground. The crew did nothing to manage these threats.

- **Fuel Remaining**
  **Recognised: yes**
  **Managed: yes**
  Due to delays at YYZ, holding was required, and the crew regularly reviewed their fuel remaining calculations. After selecting YOW as an alternate, the crew calculated their maximum holding fuel at YYZ, which was initially 14 minutes. At one stage the crew were advised of an onwards clearance time that would put the flight close to its maximum holding time. The crew twice reminded ATC that they were being vectored away from the airport. Several minutes later the crew reviewed the Air France policy for declaring minimum fuel.

- **Runway Conditions**
  **Recognised: yes**
  **Managed: yes/no**
  The runway surface was contaminated (greater than 3mm water). The pilots reported it was covered in water, producing a shiny, glass-like surface. The aircraft landing prior to Air France reported braking as poor. Autobrakes were selected from Low to Medium several minutes prior to touchdown (in response to the previous aircraft report?). The Captain also discussed the need for a positive touchdown. However, these strategies can not be considered adequate mitigation by themselves for a contaminated runway, given the runway length issue (below)



- **Runway Length**
  **Recognised: no**
  **Managed: no**
  The crew did not calculate the landing distance required for RWY 24L, despite the weather reports, nor did they include the runway length in the crew brief. The runway was 9000ft. For a landing on a wet runway, at YYZ's elevation (approx 550ft), with autobrakes Low, nil wind, full flap and no reverse thrust (which appears to be the situation the pilots initially planned), the Air France Flight Manuals calculate the landing distance required to be 7203 ft (2196m). This increases 21% with a 10 kt tailwind, to 8715 ft. Adding 'contaminated runway' to the above results in 10250 ft with thrust reversers or 11390 ft without. Passing over the threshold at 100 ft (which the crew did) rather than 50 ft adds another 950 ft to the landing (Airbus FCTM).

- **Crosswind/Tailwind**
  **Recognised: no**
  **Managed: no**
  Due to high workload and task saturation during the final stages of the approach, the crosswind threat was not recognised, nor was the change from crosswind to tailwind component. Around 1000ft the ND indicated an 80 degree right crosswind at 15-20 kts, which may be considered out of limits for a contaminated runway. Below 300 ft the wind shifted direction to a tailwind component of up to 10 kts, thus increasing the groundspeed. The crew did not notice nor comment on either of these wind conditions.

- **Reduced Visibility**
  **Recognised: yes**
  **Managed: no**
  Late in the approach, at the flare stage, the crew lost forward visibility due to rain and were looking out the side windows for runway information. This also contributed to the very long flare and deep landing. The crew had briefed the use of rain wipe but these were ineffective under heavy rain. The aircraft had rain repellent capability reinstall about three years prior, but neither crew was aware of this reinstallation.

- **Unstable/High Energy Approach**
  **Recognised: no**
  **Managed: no**
  The autothrust and autopilot were disengaged around 300 ft AGL. Due to a manual increase in thrust and increase in tailwind the aircraft arrived over the threshold about 40ft above glideslope. The PM made no callouts to indicate the deviation. After this, the control inputs and aircraft profile suggest the PF had difficulty in controlling the aircraft, and workload was significant. The approach became unstable only in the late stages.

- **High Workload**
  **Recognised: no**
  **Managed: no**
  During the final phase of the approach and landing, the workload saturated the crew, who became fixated on landing. This meant the crew were not fully aware of the wind shifts occurring, nor of how much runway was being used up, and it also impacted on the delayed use of reverse thrust. Ultimately, the high workload impacted the decision making and judgement to continue the landing.

- **Missed Approach Path Obscured By Thunderstorms**
  **Recognised: yes**
  **Managed: initially yes, finally no**
  On final approach the crew had discussed a non-standard missed approach between two large cells. However, approaching the threshold, the crew noted heavy thunderstorm and lightning activity on the missed approach path. At this point the crew believed that a go-around was no longer an option and became totally committed to landing.

- **Deep Landing**
  **Recognised: no**
  **Managed: no**
  The aircraft landed 3800 ft down the 9000 ft runway, leaving 5200 ft. The crew did not realise they had landed deep or that in the conditions the remaining runway was already already too short. Despite the deep landing, use of max reverse thrust was delayed by 17 seconds.

## Errors

There were few error management strategies applied by the crew, as most of the errors were initially inconsequential, and the full consequences did not manifest themselves until late in the approach, when the crew were already under high workload resulting in landing fixation. It is unfortunate that some of these errors had very simple procedural fixes.

- The briefing did not cover the runway length and missed approach procedure
- Runway length required was not calculated
- Conducting an approach into heavy thunderstorm activity
- Crosswind limits exceeded then landed with tailwind
- Go-around not conducted
- Deep landing
- Delayed use of Reverse Thrust
- Failure to use automation to full capacity
- Crew assumed ATC would give guidance as to landing safety

## Errors Recognition / Managements

- **Briefing Errors**
  **Recognised: no**
  **Managed: no**
  Approximately 20mins prior to landing, the approach and landing brief was conducted. The briefing did not cover the runway length or missed approach procedure- both critical items given the situation. However, non-standard missed approach options were discussed later during the approach when the crew noted thunderstorms on the missed approach path.

- **Runway Length Required Was Not Calculated**
  **Recognised: no**
  **Managed: no**
  No runway distance calculations were determined for the conditions at the

time, ie, wet or contaminated runway. Thus, the crew were not aware of the (minimal) margin for error available, nor that the margin was eliminated in the tailwind conditions. Two minutes before landing, the runway length of 2743m (9000ft) had been verbalised, although no further discussion or action occurred.

- **Conducting An Approach Into Heavy Thunderstorm Activity**

  **Recognised: initially no, finally yes**

  **Managed: no**

  Despite the threat of red radar returns along the approach path, the crew continued the approach. The error was only recognised when the crew realised the full extent of the severe weather, however by then the error was perceived as too late to manage (via a go-around).

- **Crosswind Limits Exceeded Then Landed With Tailwind**

  **Recognised: no**

  **Managed: no**

  The crosswind limitations for a wet runway had been exceeded, further adding to the workload of the crew in landing the aircraft. Then a tailwind component of up to 10kts was encountered on late finals. However, due to crew workload and distraction neither the crosswind or tailwind issue was noticed.

- **Failure to Use Automation to Full Capacity**

  **Recognised: no**

  **Managed: no**

  The PF was having a challenging time managing the speed and disconnected the autothrust at 300 ft. The pilot's mismanagement of thrust and speed lead to the aircraft being high and fast over the threshold. Leaving the autothrust engaged may have minimised this error and given the PF one less task to deal with. Further, due to the high workload situation, poor weather, and loss of visual cues near the runway, both pilots' attention was shifted outside the aircraft, thus airspeed and other instrument scanning decreased. Use of autothrust could have improved this situation.

- **Go-around Not Conducted**

  **Recognised: no**

  **Managed: no**

  The unstable approach, runway conditions, very poor weather and difficulty in controlling the aircraft during flare and touchdown were all cues by themselves to suggest a go-around. In combination, the decision became even more prudent. However, it was noted in THREATS, that the crew left this decision so late that a go-around also presented substantial risks, as the missed approach path was impacted by heavy thunderstorms. The crew had committed themselves to a landing for which they did not perceive there was any alternative action possible. The crew had flown themselves into a no-win situation.

- **Deep Landing**

  **Recognised: no**

  **Managed: no**

  The aircraft landed 3800 ft down the 9000 ft runway, leaving 5200 ft. The crew did not realise they had landed deep. However, given the runway conditions, tailwind and distance remaining after touchdown the aircraft could never be stopped in time.

- **Delayed Use of Reverse Thrust**

  **Recognised: no**

  **Managed: no**

  The PM failed to make standard after-landing callouts for spoiler and thrust reverser deployment, delaying the PF's use of thrust reversers. Maximum reverse thrust was not selected until 17 seconds after touchdown.

- **Crew Assumed ATC Would Give Guidance as to Landing Safety**

  **Recognised: no**

  **Managed: no**

  The crew incorrectly assumed that ATC would provide guidance if the weather was unsafe to land in. ATC have no such mandate.

## Undesired Aircraft States

- Too high (90 ft) over the threshold which is 40ft above G/S.
- Deep landing 3800 ft down the runway.
- Unable to stop before departing the runway end at 80 kts.
- The crew flew the aircraft into a 'no-win' situation, with both the continuation of the landing or the go-around resulting in potentially unsafe situation.

## Other points of note:

The initial CRM and communication between the pilots and between the cockpit and cabin was, for the most part, good. The pilots communicated their needs to ATC and requested updated information on holding status and weather.

Approximately 2 hours before landing, AF358 sent a revised ETA to Air France Ops in YYZ, and in return were sent parking gate information. However, the message did not indicate that Red Alert had been in effect YYZ for over 1 hour. A Red Alert YYZ was similar to a Red Lightning Warning at HKG, meaning that lightening strikes had caused ground operations to stop, although the airport was still open. Thus, there was significant terminal and gate congestion. It was not part of the Station Manager's requirement, to inform the crew of Red Alerts.

The airport operator is responsible for closing the airport or any part of the airport. Toronto Airport Authority does not close the airport for summer weather including rain, wind, thunderstorms and lightning. Although it does have procedures for closing a runway in winter conditions including ice, snow and nil braking. Airports in Canada, USA and France

**INVESTIGATION REPORT**

"Having made their decision to land, the crew used all their energy concentrate on the task and missed the cues that should have warranted review of that decision. The cues included; the runway looked like a lake; the aircraft deviated above the glidepath; the landing was going to be further down the runway than usual; the wind speed was reportedly increasing and the direction was changing; braking action was reported as poor; and the visibility became close to nil near the threshold." Transportation Safety Board of Canada investigation report (4.2.2).

(and many other countries) do not close for conditions of rain, wind and thunderstorm. However, many crew held the wrong perception that airports will close if weather conditions are too severe for landing. I'm sure many CX pilots hold the same incorrect perceptions. ATC is only responsible to ensure the runway is clear of aircraft, equipment, people and other obstacles. ATC may restrict the flow of aircraft due to particular weather conditions, but this is more to do with traffic separation on ground or on air. The ultimate decision to takeoff or land lies with the pilot.

Within nine minutes, four aircraft had safely landed ahead of Air France, all in the same high risk environment and at least one aircraft was behind them. All of these crews had elected to conduct an approach in similar conditions to Air France. This highlights the problem of hindsight bias based on outcome. I'm sure the airlines of the preceding aircraft did not conduct an investigation into such a risky approach.

At the time of the accident, Air France had a policy that a go-around decision could only be made by the Captain, regardless of who was flying the aircraft. However the First Officer had the 'responsibility' to 'suggest' a missed approach if they deemed it necessary.

## Lessons Learned

1. Have a 'go-around mindedness', rather than becoming fixated on landing. The conditions where landing fixation is greatest (ie, very high workload) are usually the same conditions that most often require a goaround to be conducted. Go-around any time a situation escapes your control or understanding.

2. Understand the large increases in landing distance due to small changes in conditions (eg., tailwind, wet/ contaminated) or crew actions (eg., slow selection of reverse thrust, high energy approach)
3. Approaches in thunderstorms and convective activity are hazardous, and the risk is increased regardless of how many successful approaches a pilot has previously made.

4. ATC do not close airports, and Airport Authorities may not close airports for 'summer' weather. Just because an airport is open, does not mean it is safe to land.

## The Aim of TEM

The aim of using the TEM process to analyse this incident was to assist other crew in learning from the event. What would you do if this occurred on your next flight?

- Review each of the threats encountered by the crew on this flight. What strategies do you have in place to anticipate and manage those threats?

- Review the errors in the same way; what strategies do you have in place to recognise and manage such errors?

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# Wind Reports – not the full story

Prepared for UK Flight Safety Committee by Robert Seaman, Senior Applied Scientist, UK Met Office.

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**Threat and Error Management [Berman(Continental) & Dismukes (NASA)] divides environmental threats into meteorology, terrain, airport and air traffic control.**

"Meteorological threats" may be defined as weather related events outside the influence of flight crew that increase operational complexity of flight, increase pilot workload and require attention and management if safety margins are to be maintained. Combining FAA/CAA accident statistics from 1995 to 2005 suggest that up to 43% of weather related aviation accidents are due to wind meteorological threats, e.g. wind shear or significant cross winds. A small sample of the aviation community (conducted by Met Office 2005-2008) provided a useful insight into pilot psychology and this particular threat. When asked to rate in order of significance, wind threats were given a moderate to low marking when compared to Cumulo-Nimbus (CB) clouds which resulted in only 2% of weather related accidents. Of course this does not mean that CBs are any less dangerous, just that pilots anticipate and recognise the threats posed by CB's better than those posed by winds in general. This could indicate that the perception of winds as meteorological threats compared to wind related accidents is disproportionate. It could be a result of a shortcoming in the communication of relevant wind information (e.g. windshear associated with microburst USAir 1016 1994, NTSB/AAR-95/03) or indeed a reduced understanding of the context of wind reports that carries forward to errors in in-flight decision making related to wind.

ICAO Annex 3 sets out the regulations for positioning of anemometers on an airfield, including measuring surface wind at a height of 10 metres (30ft) AGL, and how wind from such instrumentation is reported. It states that "the mean values of, and significant variations in, the surface wind direction and speed for each sensor should be derived and displayed by automated equipment [Recommendation]". These displayed values should be averaged over a period of time:

- 2 minute average for local routine and special reports and for wind displays in air traffic services units (ATSU). These reports must be representative of touchdown and runway.
- 10 minutes for METAR and SPECI, except that when the 10 minute period includes a marked discontinuity in the wind direction and/or speed, only data occurring after the discontinuity shall be used for obtaining mean values; hence, the time interval in these circumstances should be correspondingly reduced. METAR related anemometry provides the general flow over an aerodrome.

A marked discontinuity occurs when there is an abrupt and sustained change in wind direction of 30 degrees or more, with a wind speed of at least 20km/hr (11kt) before or after the change, or a change in wind speed of 20km/hr (11kt) or more, lasting at least 2 minutes. A different time scale is applied for gusts: "The averaging period for measuring variations from the mean wind speed(gusts) reported in accordance with 4.1.5.2c should be 3 seconds for local routine and special reports and for METAR and SPECI and for wind displays used for depicting variations from the mean wind speed (gusts) in air traffic services units. [Recommendation]"

It is important for flight crew to understand these definitions as the wind reported by ATC on approach or take-off relates to a 2 minute average at runway compared to a 10 minute average across the aerodrome that may be obtained from METAR/ATIS. The 2 minute wind report should resolve minimums and maximums in the surface wind field better and facilitate an improved decision on, for example, whether to land or go around. Wind reports may be supplemented by onboard instrumentation such as wind shear devices, with some airlines prescribing their use in standard operating procedures. However, to make best use of such information an overall understanding of wind behaviour at low-levels coupled with successful interpretation of weather forecasts and observations is necessary, improves decision making and augments flight safety.

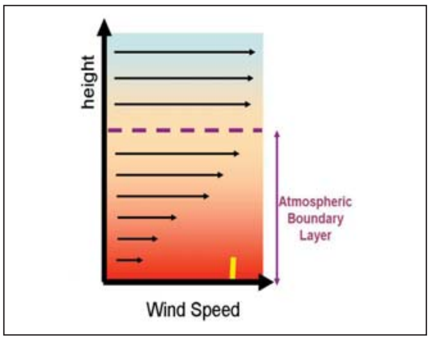


**Figure 1: Concept of wind shear within the atmospheric boundary layer. Yellow marker represents point of observation. Colour indicates temperature (red= warm, blue= cold).**

The atmospheric boundary layer is the region of air significantly affected by friction and heat transfer with the earth's surface. At the top of the boundary layer there is typically a region of high velocity air, and at the bottom (close to earth's surface) a region of nearly stationary air, figure 1 shows a schematic representation. The boundary layer "naturally" lends itself to wind shear in both speed and direction. In terms of direction, wind veers with height in the northern hemisphere, and backs with height in the southern hemisphere. Indeed many pilots are taught to appreciate these changes when applying wind correction during precision and non-precision approaches.

ICAO Annex 3 sets out the various causes of wind shear, including microburst associated with thunderstorms/cumulo-nimbus, fronts, turbulent boundary layer, inversions and topographical features. At some airports a "windshear alert" is issued on ATIS broadcasts, for example at Heathrow, where the criteria is a mean surface wind greater than 20kt (35km/hr), vector difference between the mean surface wind and the gradient at 2000ft in excess of 40kt (71km/hr) and thunderstorm or heavy showers are within about 5nm (9km) of the airport. If verified by an aircraft report, the alert becomes "windshear forecast and reported". If the criteria are met, but windshear is reported then "windshear reported" is broadcast.

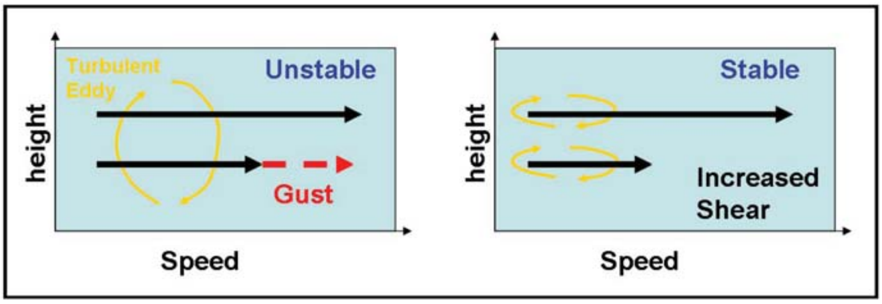


*Figure 2: The impact of atmospheric stability on turbulence and wind shear.*

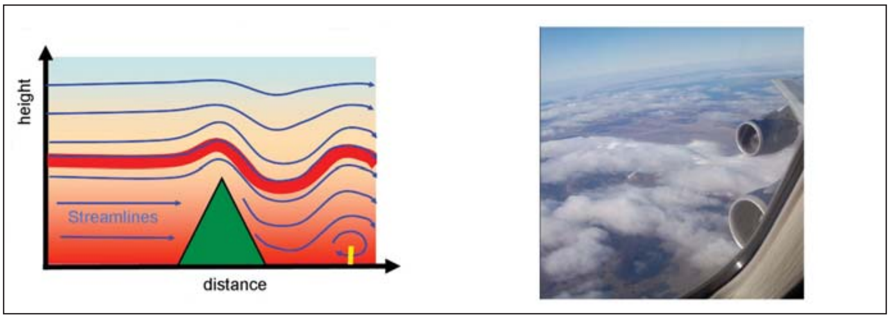


*Figure 3: [Left] Concept of mountain waves in relation to a stable layer (thick red line) of air close to hill tops. [Right] The 747 air-bridge between UK, Ascension and Falklands regularly had to consider mountain waves at the Point of Safe Return (PSR).*

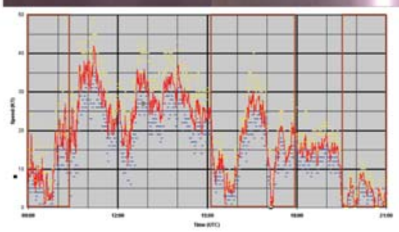

*Figure 4: Above: rotor cloud and mountain wave activity over Mount Pleasant Airfield in time order. Globally, this type of activity may occur near many airports in the vicinity of terrain.*

*Above: associated 2 minute average wind speed from airfield anemometer over period affected by rotor activity. Wind reports oscillated from variable 5KT to northerly at 45KT (a significant cross wind at MPA). (Key: red = mean speed, blue = minimum speed, yellow = maximum speed).*

The stability of the atmosphere impacts on the wind experienced by an aircraft at any particular altitude, highlighted in figure 2. Unstable atmospheres, such as polar maritime airmass, allow larger turbulent eddies to form through the vertical, resulting in occasional to frequent transfer of higher velocity air from the top of the boundary layer to the bottom in the form of gusts. As rain showers are associated with greater, localised atmospheric instability it is not difficult to see why they may be associated with increased wind shear, gust strength and frequency. Conversely, stable atmospheres, such as tropical maritime air mass, tend to suppress turbulent eddies in the vertical reducing transfer of higher velocity air between levels and increasing wind shear.
It can be seen from figure 1 and 2 that surface aerodrome wind reports do have limitations and cannot be used solely on their own. Figure 3 illustrates a case where a surface wind observation can give a false picture of the wind threat on approach, climb or during take-off. When fast stable air flows perpendicular to a mountain range oscillations are set up in the flow i.e. mountain waves. To the lee of hills or mountains recirculation may occur over an airfield, otherwise know as a rotor. In this situation, anemometers placed at different positions on an airfield may show very different readings, for example, one may be indicating light and variable and the other a strong northerly.

To illustrate this figure 4 shows a rotor cloud over Mount Pleasant Airfield (MPA) in the South Atlantic with the camera facing north towards a small mountain range that runs from west to east across East Falklands. Generally, in the southern hemisphere stable air tends to arrive from the north, on this day ahead of a warm front and with a speed of 45KT (80km/hr) at 2000 feet (AGL). Yet the anemometer at the airfield was reading variable 5KT (9km/hr) at times as the rotor passed over it and northerly 40KT (71km/hr) when outside of the rotor (fig.4). Such mountain wave activity results in severe wind shear and turbulence typically in the vicinity of the rotor cloud top affecting approach and initial climb out, in this case at about 600 feet AGL. Flight crew of the air-bridge between the UK and Falklands (fig.3) had to consider this wind threat frequently before and at Point of Safe Return (PSR) it also affected daily commercial helicopter operations. Interestingly, this type of mountain wave activity is behaving non-intuitively as the rotor retrogresses (moves north) against the strong northerly wind, highlighting the importance of understanding the meteorological context of wind reports.

Once flight crew can visualise the concept of wind variation at low-levels it is then when a top-down analysis (fig.5) of meteorological information comes into play, using weather forecasts, wind reports and visualisation in combination to increase situational awareness with respect to the weather and anticipate impacts of wind threats on handling or performance at critical flight phases. It is common to analyse weather from bottom up i.e. extracting relevant data from METARs and TAFs and then build up the

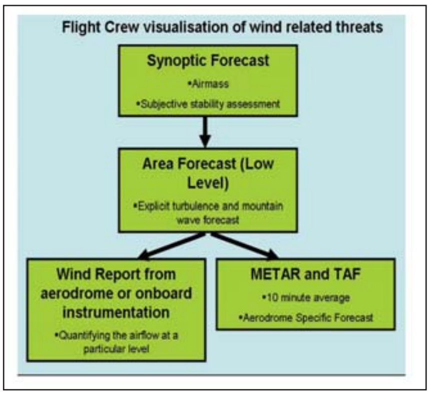


*Figure 5: Top-down interpretation of meteorological information*

bigger (strategic) meteorological picture but this is like constructing a jigsaw puzzle without seeing the picture first. By interpreting the synoptic forecast a subjective assessment of stability and airmass may be obtained quite quickly – relating the actual situation to ideas in figure 2 and 3. Using a low-level forecast enables wind threats to be identified, such as low level turbulence or mountain waves which are explicitly forecasted. This can be coupled with wind reports, data from onboard instrumentation, METAR and TAF output to quantify the impacts of the meteorological situation on wind at an aerodrome. Understanding the terrain around an airfield and the wind flow on any particularly day, coupled with forecasts then enables any wind report provided by ATC to be put into context and related to current in flight performance.

Of course a lot of this process can be applied in the pre-flight brief. In flight, that added piece of visualisation on how the wind is behaving between the surface and airborne reports, facilitated by full use of all available meteorological information, can help flight crew better anticipate significant wind shear. This brief article has defined wind reporting in accordance with ICAO Annex 3 and suggested limitations of such reports. The author also hopes it has highlighted human factors in meteorological interpretation as well as the importance to flight safety of placing any wind report in a wider meteorological context, through a top-down analysis process.

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