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Contents

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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: CHC AW139 operating in the north sea to a normally unmanned installation (NUI)

focus ON COMMERCIAL AVIATION SAFETY

Watersheds in Aviation – AF447

by Dai Whittingham, Chief Executive UKFSC

Every few years there is an aircraft accident that results in a watershed in the way we go about the business of aviation from a design, engineering or operations perspective. For example, the 1972 Staines Trident accident led to the mandatory fitment of cockpit voice recorders and a much increased focus on crew resource management, whilst Colgan Air 3407 amongst other things put the spotlight on training and crew fatigue. It is now 3 years since the Air France 447 accident and (as I write) less than a month since the BEA report was issued, but I think AF447 will prove to be another watershed moment for our industry. Less clear is the question of what lessons we will learn from those revealed directly or by implication in the official report.

Perhaps the first question to ask is: 'Have you read the AF447 report?' If not, you should do; it is easily accessible on the internet. It is not a comfortable read - the CVR transcription is sobering enough in itself, even with the knowledge that it is a translation and devoid of emphasis and tone. However, it is possible to draw your own conclusions without getting bogged down in the technical detail. I do not want to get into an Airbus vs Boeing design philosophy argument here, nor do I wish to imply criticism of any of the personalities or organisations concerned in such a tragic event, but there are things we can and must learn from this accident. Some are obvious, some less so.

Failures of primary instruments are always difficult to deal with, simply because with all other forms of failure we have the instruments to tell us what the aircraft is actually doing. I recall with clarity an incident at night during my first tour on the Phantom. As I reduced power and levelled off at 15,000ft IMC somewhere over the North Sea, the airspeed dropped from 400kts to less than 150kts in 3-4 seconds and then drifted down to zero. At 200kts, an audio attention-getter sounded – that would be my navigator shouting "Unload!!" at me. I opted instead to take a more detailed scan: main and standby attitudes agreeing wings level and zero pitch, VSI just off zero, altimeter not moving any faster than normal, a low indicated angle of attack, and both engines at 85%ish. Answer: do nothing.

As it turned out, a pitot-static tube had been trapped when the radome was closed, hence the ASI failure. A night close-formation approach ensured we didn't overstress gear or flaps (although you could fly an approach quite happily using just AOA) and all was well. But then, I was lucky – I had been trained for just such an eventuality. The relationship between power, attitude and airspeed had been drummed into me during my basic flying training and one QFI had even made me fly a live instrument approach with the ASI covered.

Not all of us have the luxury of such comprehensive training, and financial pressures will continue to drive us towards doing sufficient training and no more. But how do we know when we have arrived at the 'good enough' point? Where does the crossover between on-the-job training and increased operational risk occur? Should that vary depending on whether you are flying long-haul passenger ops or short-haul business? What is the right balance between automation and manual skills? And who decides?

With natural tension between training and cost, are we making best use of our simulators? The success of ATQP aside, there is heated debate about using sims for any upset recovery training that goes beyond the normal performance envelope, and there are some who argue against any sort of stall training. I agree that the performance of an aircraft in untested regimes can't be predicted with the accuracy required for Level D simulation, but does that matter? My <u>personal</u> view is that it doesn't – I think in this instance there is some truth in the adage 'fidelity for the mind, not the hands'. The dynamics of an upset are likely to vary so markedly with weight and altitude that training for all eventualities simply becomes impossible. Instead, I suggest it would be better to give people experience of the process and broad principles behind upset recovery rather than trying to generate the sort of fine motor programmes appropriate for, say, a rejected take-off. And it need not take long: 5 minutes of upset recovery training during a sim detail would in my view arguably be a better use of time than flying yet another instrument approach.

I acknowledge that cost (and possibly time) will always be an issue, but I believe the regulator has a duty to act when additional training needs are identified. Without regulatory pressure, even in guidance form, the battle for the necessary resources is not likely to be won at a time when the industry is operating to such tight margins. And yet the 'do nothing' alternative might just result in a hull loss, which is in nobody's interest. So when you read the AF447 report, think hard about training and your own experience - could this accident happen to you?

Information Exchange and Safety Culture

By Capt. Neil Woollacott, flybe

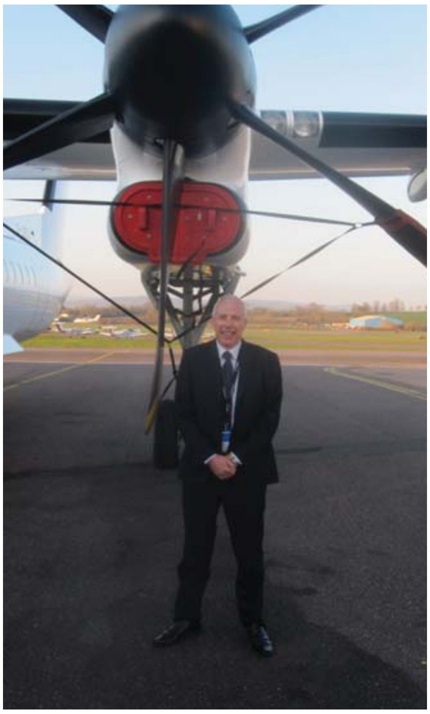
This is my first Chairman's Column. I would like to thank my predecessor Tony Wride for all the good work he and the team have achieved in his tenure. I hope that I can step up to the mark that has already been set.

The last twelve months has seen yet more economies in the aviation industry as operators in all sectors attempt to cut their costs to a minimum. I have to say that our members have undoubtedly been affected by these economies, the membership the UKFSC has been affected by some small degree. While this is disappointing, it is still seen by the industry as a worthwhile group contributing to our collective safety.

I believe that one of our biggest contributions to this safety is the Safety Information Exchange. We are able to gather every few months and discuss our own mutual problems. The unique aspect of these discussions is the presence of the Regulators in the same room, and the willingness of all Members to speak about anything, even if it might reflect on their own systems of work. The same approach can also be used by Operators, whether they are involved with aircrew, engineers, ATC or any of the many Service Providers in Aviation. The regular safety meetings should reflect the same culture that the company is trying to engender in their employees. The fact that Senior Management is attending the same meeting should not impede discussions of any nature that are considered to be of significant safety interest. It is, understandably, sometimes difficult for more junior members to assert their ideas when faced with a sea of 'management' faces. This is where the tact and diplomacy skills come to the fore in order to get your message across! Open reporting cultures can only do well if they are not only used, but also seen to get responses.

There has been much going on in the industry with security-related issues and this has inevitably had some impact on Flight Safety. I have maintained over the year that, whilst we must be conscious of security implications on our sector of the industry, as a Committee of Safety Professionals, we must be careful not to be drawn into areas that are already well served by experts in their field. I still believe that this is the right approach; after all, we have access to probably the best information in the industry and are able to find out any security issues that give us concern. We will, however, still continue to monitor any changes to security that have a direct effect on Flight Safety.

This has been a year of change in the industry and, after a few dark times, perhaps there is now a brighter horizon in view. I believe that the work that we do on the UK Flight Safety Committee only serves to enhance our position in the industry and we should continue to flourish as an important part of the improving safety culture that is happening throughout the industry. Let's keep spreading the word.



UK FLIGHT SAFETY COMMITTEE OBJECTIVES

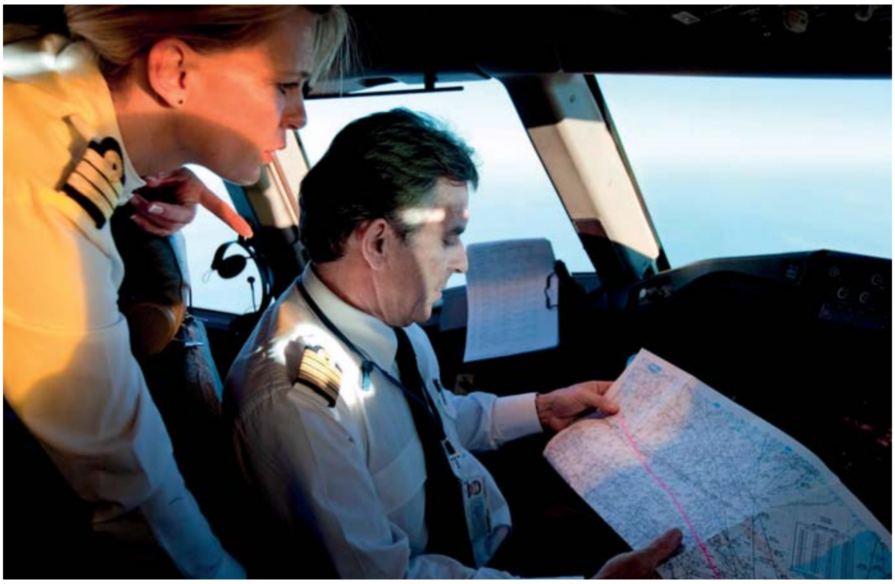
- **To pursue the highest standards of aviation safety.**
- **To constitute a body of experienced aviation flight safety personnel available for consultation.**
- **To facilitate the free exchange of aviation safety data.**
- **To maintain an appropriate liaison with other bodies concerned with aviation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

Re-engaging the Pilot

by Chuck Weirauch considers how a new focus on training is called for to address automation accidents and incidents.

In light of the Air France 447 and Colgan Air 3407 autopilot disconnect-related accidents, along with a rising number of flight deck automation incidents, regulators and the aviation industry as a whole are taking a much closer look at how well flight crews are trained to respond when the computer-controlled aircraft does not act in the manner expected by the pilots.

While an emphasis has been placed on the further training of manual flying skills to more properly respond to automation-related events, some question whether such additional training measures fully address the root of the perceived disconnect between the pilot and the automation.



Above: Has the pilot now become the back-up to the automated systems on the flight deck? Image credit: Air France

Root Issues

According to Flight Safety Foundation President Bill Voss, there is a more fundamental root issue that has been advancing throughout commercial flight operations over the years without much recognition of it, and this has directly led to the increase in flight deck automation accidents and incidents. That problem is that the industry had not seriously taken note of the fact that instead of the flight deck automation serving as a tool to assist the pilot in the operation of the aircraft as in the past, the pilot has now become the backup to the automation in the airplane, Voss said. This means the pilot's job has fundamentally changed, but we have not recognized this change nor designed training for it, he explained.

"We have gotten ourselves into a position over the past 20 to 30 years that is pretty serious," Voss said. "There is no point in ever debating the merits of automation that has saved countless thousands of lives, but as we have introduced it, we have never stepped back and considered what this highly automated environment would do in terms of disengaging cognitively the pilot from the operation of the aircraft. Now we are confronted with this in a way that we can't ignore in light of such accidents as Air France 447."

While the expansion of manual flying training is a good step, such an emphasis overlooks the fact that the core of the flight deck automation issue is really a cognitive one rather than a manual skills one, Voss pointed out. One answer is to find a way to better engage the pilots while enroute so that they go through different scenarios and visualize the state of the aircraft as it goes through the various stages of the flight. In this way the pilot is actually ahead of the aircraft and is continuously anticipating the next aircraft action, he said. One analogy could be how an alpine skier might visualize going through a downhill slalom course before a run.

"We have to do something to be able to re-engage the crews with the operation of the aircraft, because right now they are dangerously disconnected," Voss emphasized. "Because the pilot's job has fundamentally changed, this means that we have to go back and do a whole different type of training, and this may be even something in the flight deck such as continuous embedded simulation-based training. Perhaps you pull out your iPad and run four or five scenarios while you are in cruise flight instead of just going through a top-to-descent checklist, for example."

However the new kind of training is developed, the aviation industry cannot consider the automation issue to be just a training problem that can be resolved in a two-day course over a year's time, Voss was quick to point out. Rather, it is one that requires employing the means to keep the pilot cognitively aware of the operation of the aircraft while flying throughout his or her career, he emphasized. "Rather than just those two days of training, we have to focus on the thousands of hours crews spend doing nothing while in flight," Voss summed up. "Somehow we have to turn this into learning time, and that's the challenge. That's why this is not just a training thing."

Improving Automation Training

While John Cox, President of Safety Operating Systems, does not feel that traditional flight crew automation training is inadequate, he does feel that it should be improved upon. One of his recommendations is to extend the amount of time airlines specify for a new hire pilot's initial operating experience (IOE). This opportunity may be the direction in which the aviation industry should head, since flight simulators and ATDs do not have the capability to accurately recreate the entire real-world environment, he suggested.

"We are giving people the bare basics on automation in simulator and advanced training devices during their initial training," Cox said. "So when they go out to the line during their IOE, that's when they begin to put that basic training into use. And this may be an area where we can expand on this basic training. In this way, pilots get an opportunity to use the automation in a real-world environment, while still being supervised by a proctor."

Cox also advocates making recurrent training more line-orientated, which is the whole idea behind the Advanced Qualification Program (AQP) concept. This approach allows the opportunity to improve on both manual flying and automation skills. Taking real-world airline data and applying it to operational scenarios as is done in AQP recurrent training is a fundamental difference in the way the industry traditionally trains its pilots, Cox added.

Another approach is to have pilots switch the autoflight system to a much more basic mode until they have sorted out the reason for the unexpected result, Cox said. However, studies show that in some automation scenarios pilots are reluctant to take this action to reduce the number of variables in the unexpected event equation. Regardless of the approach, the airline industry needs to find a way to address the issue of the increasing number of automation-related accidents and incidents, Cox emphasized. This is also because automation issues of ten years ago, such as unexpected mode reversions, are still being reported today. "We have to recognize that we are seeing too many cases of failure to understand what the automation is doing," Cox summed up. "So the question of how do we take this opportunity and what we do with it is a pretty fundamental one. And I hope that we as an industry are smart enough to succeed with it, not just talk about it."

Design and Training

Another root cause for automation accidents and incidents can be the highly complex automation interface in the cockpit, one that "can be, and often is, a breeding ground for errors," as Cox pointed out. To help resolve this problem, human factors design experts inside and outside of the aviation industry are both studying how people deal with complex systems and employing modeling and simulation to integrate human-in-the loop avatars into human-centered designs for improved computer interfaces and flight data displays.

According to Guy Boy, Director of the Human Factors Institute at the Florida Institute of Technology and former Airbus human factors designer, the Institute is trying to understand what new visualization techniques, including 3D and head-up-displays, along with iPad-like computer interaction, would prove useful to better provide flight management system data to the pilot. Another focus is on how best to present weather information to the flight crew.

In highly automated cockpits, the pilot's job is really one of systems manager more than pilot, Boy said. So the whole concept of systems management needs to be better understood in order to help reduce accidents and incidents through improved cockpit design, he explained.

"Systems integration is something that really needs to be addressed in flight deck automation design," Boy said. "We also need to learn how to deal with crisis management, so that during an unexpected automation event, we know how to manage it."

A part of the systems management problem is a lack of understanding by pilots of how the flight deck automation system works, Boy pointed out. The problem is exacerbated by the fact that our society focuses on training people on the rules, while the aviation industry focuses more on skills-based training rather than knowledge-based training, he explained.

"So how do you deal with the unexpected?" Boy asked. "This is more of a problem today as systems become more complex. This is where skills-based and knowledge-based learning come together. Skills-based learning is more for the expected outcomes.
So in this case (unexpected automation outcomes) knowledge-based behavior is extremely important.

We need to better teach how the system works. So what should we teach and to what complexity? This is the difficulty and what we need to better understand.

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TEM's Unspoken Language

Acting on subtle trouble clues is an essential element in the process of defeating developing risks

by Thomas R. Anthony

There is an unspoken language, although sometimes it ripens into discussion, associated with the threat and error management (TEM) process. It is a simple language of just three "words." Commonly known and widely used, these words have a connection to the world of TEM that has gone unnoticed. The three words are: Huh?, Whoa! and Phew!

From the aviation safety perspective, the word Huh? is the most important; the others flow from it. There are two common usages of the word Huh. The first is "Huh. I didn't know that." The second is "Huh? I wonder what that is." For the purposes of TEM, we are only interested in the second. So why are we interested? Because this word is an identifier of a potential threat or hazard.

We utter Huh? when something doesn't make sense, when we hear a sound or experience a sensation that we cannot explain, or observe something that we didn't expect.

Huh? is an involuntary word. Something has happened, and we can't figure out what it is. The occurrence may not be dramatic enough to demand our immediate attention, but in the world of aviation safety, the word Huh? should not be ignored. Like a piece of yarn tied to the shroud of a sailboat, it is a telltale, an indicator that something changed, perhaps for the worse.

Huh? is an indicator that a threat or a hazard may be present. While not a red flag, it is often a yellow flag that requires our attention, or a warning to proceed with caution. As aviation professionals, everything should make sense to us. When something doesn't, the reason needs to be found.

When things don't make sense, the minimum action is to vocalize and identify the situation in a question: "That frequency change doesn't make sense" or, "Why would they assign that runway?" Recognition and vocalization drags the Huh? moment out of the realm of a "vague sense of unease" and places it squarely on the table for resolution or confirmation by ourselves and others.

At the very least, vocalizing the Huh? starts the process of cautionary mitigation — "I guess we should look at this a little closer," or "I guess we should confirm that frequency." In a way, Huh? serves as a probabilistic risk assessment, another good reason that verbalizing such a condition to others can help mitigate and manage the associated threat or hazard. Upon the announcement of the word Huh? there exists at least some cognitive processing of whether this new thing represents a high level of risk, launching a proactive risk assessment that seeks to complete the risk matrix in real time, followed by mitigation development.

Why is this important? Often, when performing a demanding operation or task, our attention is focused on a single thing, or a set or sequence of things. The temptation is to continue with the attention-demanding task until it's completed. But in doing so, we may ignore the relatively undemanding — at least immediately — circumstance that has generated the Huh? feeling. This myopic task fixation would, of course, be the wrong response. Similarly, another wrong response is: "Oh, it's probably nothing," without investigation. Ignoring the Huh? can be as detrimental as excessive attention to a singular task.

So where do these Huh? sensations come from, and why are they important? Sigmund Freud, often called the father of psychoanalysis, explains the mind in terms of three levels of awareness: the conscious, the subconscious and the preconscious. He distinguishes the preconscious from the subconscious as follows:

[There exist] two kinds of unconscious — one which is easily, under frequently occurring circumstances, transformed into something conscious, and another with which this transformation is difficult and takes place only subject to a considerable expenditure of effort or possibly never at all. ...We call the unconscious which is only latent and thus easily becomes conscious, the 'preconscious' and retain the term 'unconscious' for the other.[1]

When we perform a demanding task that requires our complete attention, we are operating at the conscious level. We are not aware of everything that is stored in our memory, since everything that can be recalled is the preconscious.

I believe that the Huh? phenomenon is the recognition that something doesn't make sense on the preconscious level. The preconscious comprises all of the experiences and lessons we have logged. For aviation professionals, this represents a significant mental database. So, while we are not aware in the present moment of all that we have learned, that information is stored in our preconscious, just out of sight, so to speak. It is similar to the phenomenon of a difficult-to-remember name popping into our mind, that event indicating there was processing going on at the preconscious level. It is this preconscious processing that is responsible, I believe, for the Huh? phenomenon. We ignore the Huh?s at our peril. People have recognized this phenomenon over the ages. Family members are advised to "sleep on it" before making any big decisions. Why is this good advice? It allows us to use the lessons, information and values that are in the preconscious, which are not immediately available to us while we are talking with the salesman at the used-car lot.

The Second Word

The second word in the unspoken language of TEM is "Whoa!" While punctuation is dependent upon context, the word Whoa is almost always followed by an exclamation point, as in "Whoa! What the heck was that?" Whoa! is a relatively simple word compared to Huh? Its importance in the world of aviation safety is that it is the word that may follow when the first unspoken word (Huh?) is ignored.

While we call it a word, it is better described as a spontaneous utterance, a class of speech given a special status in the eyes of the law of the United States. As with many legal concepts, there is a Latin term for spontaneous utterance; it is res gestae. The spontaneity of such utterances is judged to be of such genuineness that they may be reported by others and taken as evidence in a court of law.

So what does that mean to us? Like Huh? the word Whoa! is an automatic verbal signal. It is the immediate and automatic recognition that a threat or hazard condition exists or has just existed. It lacks, however, a complete element of cognizance of what the hazard really is, as in the earlier "Whoa! What was that?"

The Third Word

The third word of the unspoken language is Phew!, the natural follow-on to Whoa! It is uttered after the threat or hazard has passed, and it reflects a certain degree of understanding of the threat or likelihood and the severity of the threat or hazard condition, and indeed the acceptable outcome of the risk event. In most cases of Phew!, the likelihood was close to 100 percent, and the appreciation of this is clear and inescapable.

In this sense, Phew! functions as a rapid risk assessment of a historical threat or hazard — a verbal, determinate risk assessment process, including outcome.

While there is often very little that can be done following the utterance of Whoa!, Phew! (like its cousin Huh?) presents very real opportunities for significant safety action. Like Huh?, however, we ignore the Phew! utterance at our peril. Unless the Phew! moment is followed by analysis of what caused it, as well as a mitigation of those causes, a sort of real-time root cause analysis, the original hazards that started the Huh?, Whoa!, Phew! chain remain unchecked. The absolutely wrong response to Phew! is: "Phew! That was close, but I'll be fine from now on." The correct response is: "I've got to figure out why that happened and change something."

Words in Action

Cmdr. Chris Nutter, in his previous career as a U.S. Navy A-7/FA-18 pilot, recounts the following story: He and a wingman were blazing southbound on a low-level training route in the Panamint Valley desert of California. With things happening very quickly, Chris sensed a Huh?, followed immediately by a significant deceleration.

Immediately, he heard his wingman announce over the radio, "Whoa!" Nutter responded "What do you mean, Whoa?"

The wingman answered quickly: "Yeah, you just lost about 6ft of your tailpipe," a confirmation of the condition that prompted Huh? As the aircraft lost most of its thrust and was rapidly losing airspeed, Nutter traded the speed for altitude for either a one-time shot at essentially a no-thrust landing or positioning the aircraft to allow a controlled ejection in a safe area. In the end, Nutter landed safely at China Lake, a Navy airport.

Nutter, now Capt. Nutter with Alaska Airlines and a University of Southern California (USC) aviation safety management instructor, adds: "Effective threat management techniques can include a conscious awareness of the secret words, and a crew agreement that when they arise, they are verbalized and addressed by the crew."

This is a proactive risk management process in real time. But, by the time Whoa! happens, the crew is committed to managing either an error or hazard that now demands immediate attention and mitigation, and deliberate action to restore reduced risk levels. In some tragic accidents, while there may have been a Huh? there may not have been sufficient time between Whoa! and impact to resolve the situation.

These three unspoken words are an effective articulation of the need for real-time risk management, with direct relevance to modern safety management. The word Huh? validates what many pilots for many years have said when "something doesn't feel quite right." Often, things are not right, indeed, and the operation needs attention — identification, mitigation and resolution. Recognition of the "Huh?" and implementing appropriate risk management are real, effective methods of assuring operational safety.

Another Word

A careful reading of Nutter's incident reveals that his Huh? Whoa! sequence did not end in Phew! It ended in something akin to "Oh, Jeez," "Darn" or a more salty expletive. The reason that these types of words are not included in our TEM lexicon is that they take us outside the realm of threat and error management. They belong instead to the realm of crisis management, emergency response or recovery. If we fail to control the threat or hazard early, to some extent we may become controlled by it.

Other Examples

Dr. Gregg Bendrick, a U.S. National Aeronautics and Space Administration flight surgeon and an instructor in the USC Aviation Safety Program, notes that the human eye possesses mechanisms that function in a way very similar to the Huh? Whoa! Phew! model. The retina of the human eye contains two types of sensory elements: rods and cones. The cones — so named because of their conical shape — are concentrated in the center of the retina. The rods — also named because of their shape — are dispersed over the wider area of the retina with a much lower level of concentration. The cones process visual information for our central vision. The central vision is what we see and are consciously aware of. On the other hand, the rods process information of the peripheral vision. In effect, the rods — the peripheral vision — act as a light and motion detector, as well as a basic horizon indicator (Figure 1). We can "see" things via this peripheral vision but may not be consciously aware of them.

The peripheral vision helps with our overall spatial orientation, and when a light or relevant motion "catches our eye," our brain redirects the eyes to focus the central (cone) vision onto the item of interest. That is, the item is now brought to our conscious awareness.

The rods, and therefore the peripheral portion of vision, also combine with input from the vestibular structures of the brain that help control balance. This duality of vision also allows us to walk while focusing our central vision on things like reading a newspaper or viewing an iPod. We may not be conscious of the walking function, nor the general surface of the walkway ahead, but it is being subconsciously processed.

The rods, however, possess a very important Huh?-like function. They sense movement and environmental differences, and they act automatically to direct the central vision to focus on the item identified to need further attention. In a sense, it is a physiological TEM function.

Understanding a little more about rods and cones gives further insight into their distinct but dependent function. The concentrated cones that feed our central vision are able to make acute discriminations among objects, so that's where the eye's best vision can be found, 20/20 or better. Visual image acuity for peripheral vision via the retinal rods is limited to 20/60 at best. Similarly, cones can distinguish the full color spectrum, while rods can detect only a single green-blue color. This central vision/conscious mind, peripheral vision/unconscious mind duality explains the

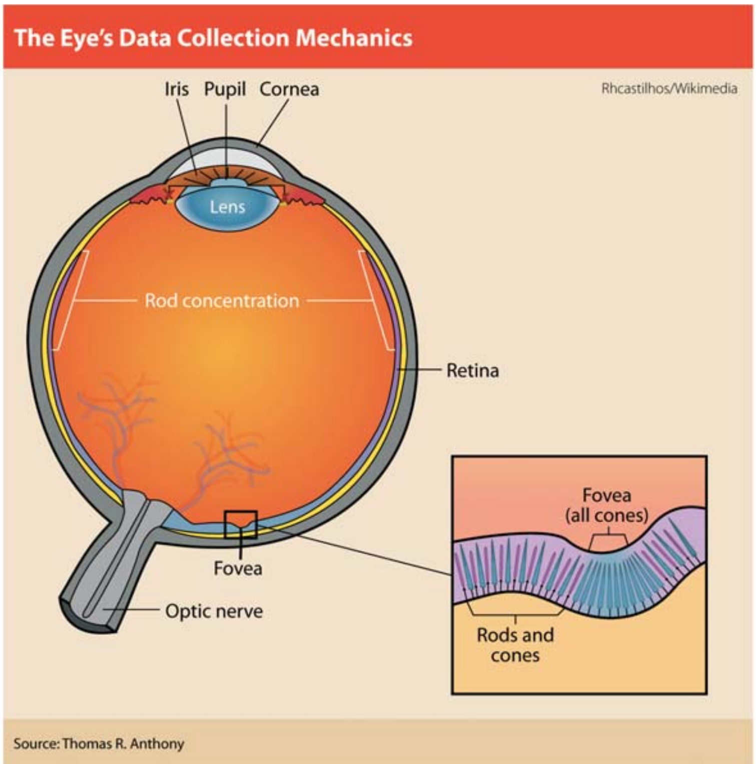

Figure 1

"invisible gorilla" phenomenon that many of us have witnessed when watching the popular video used to demonstrate selective vision. Students are told to count the number of times a basketball is passed among members of a white-uniformed team. The video is played, and the white team passes the ball about 20 times. While the ball-passing activity takes place, a person dressed in a gorilla suit walks among the players. After the video is played, the instructor asks how many people saw the gorilla and is often met with the question "What gorilla?" from a large portion of the class.

Insight into the dual functions of the eye lets us understand that the invisible gorilla phenomenon is not just a matter of attention but is also a matter of physiology as well.

This rod-based peripheral detection capability is a physiological component of the unspoken word Huh?, and it highlights how important it is to consciously risk-manage our Huh? events.

Useful Lessons

The first lesson is to understand that the Huh? phenomenon is an indicator that a threat or hazard may exist. The fact that we aren't able immediately to determine what created the Huh? effect is not important. Capt. Guy Woolman of Southwest Airlines describes the Huh? feeling associated with an unusual sound as: "The airplane is talking to you. Better listen."

It is important to understand that the Huh? phenomenon is a result of the fact that the mind, like the eye, is not conscious of all that it knows at all times. We experience this from time to time when we cannot immediately recall a name. Trying harder seldom gets us closer to remembering. However, when we set the task aside and think about something else, the memory often pops up like a cork on the surface of a pond. Our mind has been working on the problem unconsciously — or subconsciously, I don't know which. The conscious mind is not always the most direct link to remembering. But the important thing is to recognize that this is the way the mind sometimes works.

As Nutter says, the most important step after Huh? is to verbalize the concern and then seek additional information.

Questionable Words

Certain phrases are often associated with a less than productive approach to TEM. Among them are:

- "I can handle this." This is often associated with the recognition of an increased hazard level with no accompanying mitigation other than increased concentration of the type that can cause us to miss the gorilla.
- "Gulp." This is associated with recognition of an increased hazard environment and no mitigating measures.
- "… No matter what." This gives permission to all who hear it to depart from standard operating procedures (SOPs), regulations and established safety standards in order to meet a single threat or hazard. It is inherently a hazard-creating statement, and is not easily withdrawn.
- "Hey, watch this," or "I bet you've never seen this before." These are phrases that almost certainly precede a hazardous act, an intentional noncompliance with SOPs, regulations and established safety standards, and within another frame of reference are a significant contributor to the automobile insurance rates charged for teenaged males.

So, follow through in examining the Huh?s encountered and pay attention to what the Whoa!s and Phew!s tell us about what just happened; these are processes that are at the heart of TEM.

Capt. Chris Nutter contributed to this story. Thomas R. Anthony is director of the Aviation Safety and Security Program at the Viterbi School of Engineering, University of Southern California.

Notes

1. Freud, Sigmund. New Introductory Lectures on Psychoanalysis (1932).

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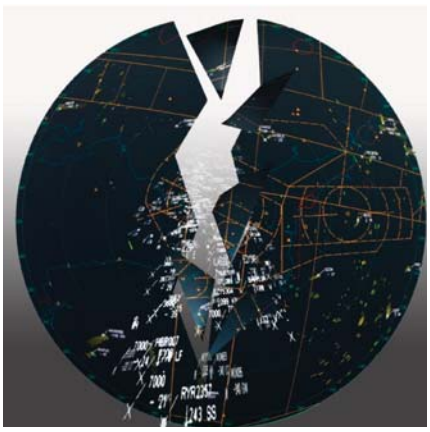
Emergency and unusual situations – whose world view?

by Anne Isaac, NATS

We have always known that wise people learn from their mistakes and that all groups of specialists from medical surgeons to elite athletes, can relate how, when things go wrong, they learn from reviewing the circumstances of their actions.

The giant slalom skier who misreads a turn through a gate and tumbles down the side of the run, the Olympic diver who mis-times their exit from a multiple twisting somersault, and the rally driver who trusts in the friction of their high performance car on a slippery road, all reflect on the moment they lost control. At the point that the pre-programmed motor sequence of these highly skilled actions is being executed the human has little to do but wait for the outcome. In the examples above the sequence of motor programmes has been disrupted by inputs which were adaptive; weighting too much on one ski, initiating the twist a nanosecond too soon and compensating for a wet surface too late. What few people realise is that the brain will now have learnt another slightly different sequence from the original motor programme which it will match to the new context, if the same circumstances are encountered. I will return to this later in this paper.

These are all examples of split-second adjustments made when things go wrong, but what of the situations in aviation, with which we are typically more familiar, and in which we often have a slightly longer time frame to recover. Interestingly, humans usually have a similar response to unusual or emergency situations and these follow a set pattern - indeed they can be found in any traumatic response. Firstly we have a shock or startle reaction, and the strength of this will depend on how many times we have encountered this situation before. At this point we will suspend belief, for a moment (classically we look to any other person in the direct vicinity for confirmation that what has just been experienced is shared).



Once it has been established that something has indeed gone wrong, we attempt to compare the situation with past experiences and start a sequence of pattern matching and decision making. It is at this point that the brain defaults to the situation explained above, and the outcome often relies on the quality of unusual circumstance and emergency training, experience and the ability to accept what the facts of the situation are rather than what we would like them to be. This final response is a very strongly developed behaviour which promotes survival in extreme situations, but this behaviour often leads us to ignore the unusual facts in favour of disbelief since we want and need a safe outcome. An example of this was the response of the air traffic controller when confronted with a MAY DAY call from the British Airways aircraft flying through an ash cloud and announcing that they had lost all 4 engines. The air traffic controller clearly disbelieved the situation and responded with an acknowledgement that the aircraft had lost No. 4 engine.

Knowing how humans respond to unusual or emergency situations has led airline companies and manufacturers to support crews with emergency checklists with which the pilots can eliminate the possible failures in a systematic manner. This leads to a more comprehensive approach to tackling these situations and, typically, supports a safe and expeditious outcome. However there will still be examples in which highly trained crews simply don't believe the indications from instruments and tragically their training, as individuals or crews, leads them to disbelieve what is presented to them. In extreme cases they may even ignore the warnings. In the air traffic environment such aide memoires and checklists are less evident, however training in unusual circumstances and emergencies is practiced with regular periodicity.

History would suggest that it is not until an incident occurs, and which is attributed to both controllers and pilots or vehicle drivers and is investigated jointly, that it is acknowledged how little each professional group knows of the other, particularly in an emergency or unusual event. There are fewer and fewer opportunities in the training of all parties to share common training scenarios. As a result knowledge regarding the 'world view' of each team is often unknown or misunderstood.

But first we need to appreciate the different 'world views'. A controller's responsibility is focussed on separation of individual aircraft (although often they will consider aircraft in pairs or in some cases multiple pairs); however they have many of these to consider and as such, arguably, their world view is a 'many to one' dynamic. By contrast, pilots are responsible for the safety and security of their aircraft and as such their flight is associated with a 'one in many' dynamic. Both the controller and the pilot seek the same safe outcome but their perspectives or 'world views' will differ and as such their priorities may be misunderstood, especially in an emergency.

One way to support a better understanding of these two professional groups is to put them together in a facilitated workshop to explore the issues faced by each team in unusual and emergency situations. At NATS, our considerable experience of Multi-Crew Resource Management workshops has included the following discoveries:

What pilots should know about controllers:	What controllers should know about pilots:
■ The priority for controllers is to - communicate - calculate - co-ordinate	■ The priority for pilots is to - aviate - navigate - communicate
■ Although controllers will probably have more emergencies in their shift cycle than pilots, they remain uncertain if they are not given what they perceive as essential information. Their priority in an emergency is to move any conflict traffic which means their workload increases in the area of communication and co-ordination. A good example of these different priorities can be heard in last R/T exchange from the US Airways airline (Cactus 1549) which ditched in the Hudson River	■ Many airlines use an emergency acronym to brief essential crew which helps simplify the communication exchange. One example is the use of a NITS brief which includes – - **N**ature of the problem - **I**ntention - **T**ime needed – to sort out the problem - **S**pecial instructions if required ■ The priority for the pilots, depending on the emergency, is to fly their aircraft and inform their crews about intended decisions. Often ATC is low on their priority in the first minutes of the emergency
■ Selecting 7700 helps controllers to identify aircraft who need 'special attention' or have an emergency. Controllers will treat all 7700 squawks as needing priority and arrange their traffic accordingly. The other advantage is that the 7700 squawk is also 'seen' on radar by all controllers throughout their airspace which increases their situation awareness and readiness to assist	■ At all times, but particularly in an emergency, pilots prefer to be given distance information – in miles, not periods of time – in minutes ■ Pilots have advised that they find it very helpful to receive ATC guidance that is prefixed or suffixed with the statement "when able"
■ Controllers will assume pilots will announce "PAN PAN" for special attention regardless of the outcome. Controllers will assume pilots will announce "MAYDAY MAYDAY" when requiring immediate support. Both 'PAN' and 'MAYDAY' announcements carry almost equal attention and the controllers will allocate a dedicated controller and frequency if required	■ 'PAN' and 'MAYDAY' does not necessarily mean a pilot needs immediate landing or the nearest airfield ■ Pilots also advise that in most unusual or emergency situations they prefer to be given airspace to sort themselves out. The only exception is in an explosive decompression or smoke/fire in the flight-deck or cabin

Common information for both crews/teams:

At all times, but particularly in an emergency, the 'world view' of the two crews/teams differs. This clearly dictates the priorities of the two parties and therefore the reason these situations can be difficult to manage. In these situations each team can lose overall situation awareness of the other team and this may introduce unwanted communication and this uncertainty may increase stress for each team.

In emergency or 'go-around' situations, which require an immediate climb/descent, different fleets within the same airline) may fly a profile not anticipated by the controller. straight ahead climb/descent and some prefer a turning descent. What an airline/aircraft type requires and what controllers expect they want, or will do, are often completely different.

Finally, let us return to the phenomena of motor programmes and the recognition of unusual or emergency situations. The response of the brain, and the consequent behaviour, is always a result of experience and expertise. Once any professional has learned the basic skills, rules and procedures of their work they will have sufficient knowledge to work in a normal situation. However once an unusual or emergency situation is presented, the person will be limited in their response and also subject to several decision-making, behavioural biases. These include any the following:

- **Frequency bias:** The risk of an event occurring is almost always over or under evaluated because evaluation is based solely on reference to personal experience;
- **Selectivity bias:** This occurs when, as we select information, our preferences lead to a strong tendency to select a restricted core of facts;
- **Familiarity bias:** This is a tendency to choose the most familiar solution, even if it is not the optimum solution for the situation;
- **Conformity bias:** This happens when we look for results which support our decision rather than information which would contradict it;
- **Group conformity:** This is a bias due to group pressure 'Group Think' and/or a tendency to agree with a majority decision.

Although expert decision makers may make small errors, they generally avoid large mistakes. They seem to have discovered that for many decisions, coming close is often good enough: the key is not to worry about being exactly right, but to avoid making really bad decisions.

We can recognise all of these decision making bias in the recent aviation accident reports both in Europe and beyond. It is therefore essential that all aviation crews and teams are exposed not only to 'normal' unusual or emergency situations, but also the recovery from unexpected and unforeseen situations.

This has become even more important since both professional groups are increasingly exposure to highly automated systems demanding more monitoring and perhaps less 'hands-on' collaborative activity.

As on nearly every manned flight since 1965, lift-off of Apollo 12 went smoothly - but only until seventy-eight seconds after ignition when, unknown to anyone, including the astronauts on board, the booster was struck by lightning. Pete Conrad radioed down the alarming news that the bottom had fallen out of nearly every reading on every electrical system aboard his ship.In the seconds following in which the abort decision would have to be made, John Aaron in Houston took another look at his screen and noticed that the readings on the console were showing about 6 amps, well below what they should have been, but well above the zero that would be expected if the system had truly failed. It had been a few years earlier, when he was monitoring a simulated countdown of another mission, when he had seen a similar pattern as the rocket accidentally tripped the circuit breaker on its telemetry sensors. In a split second, and with conformation from flight command, John Aaron pushed the reset switch and instantly the numbers were restored. Minutes later Apollo 12 was in Earth's orbit and went on to complete a successful mission to the moon.

Lovell & Kluger, 1994.

Scenario Training for Aircrew and Controllers (STAC) – General Information

As part of the on-going training undertaken throughout NATS, there is a desire to expand the TRUCE and continuous professional development of operational staff. As part of this development SRG have approved the expansion of the licensing requirement of TRUCE to include more pilot/controller interface activities. These will include controllers joining with pilots in LOFT experiences and a new workshop based activity known as STAC.

The objectives of STAC will be to offer pilots and controllers a forum to explore the risks and hazards inherent in emergency situations.

The workshops will be facilitated by NATS TRM Specialists and airline CRM instructors and follow structured discussions relating to:

- Communication issues within and between the flight-deck
- Sharing situation awareness in an emergency scenario within and between the two groups
- Issues of overload and decision making for both crews
- Issues of handover between controllers and sharing the situation within the aircraft teams
- The use of SOP's, including emergency quick reference checklists by both groups

The workshops will use actual emergency scenarios which will endeavour to bring a clearer understanding to both groups of the separate and often competing demands, in unusual and emergency situations.

The workshops will be held in a variety of venues which, to date, include Swanwick, Farnborough and Gatwick.

All enquiries about attending these workshops can be directed to Anne Isaac (anne.isaac@nats.co.uk) or to Michele Robson (michele.robson@nats.co.uk}

Travel expenses should be paid and you'll get a free lunch. The dates when pilots are needed are:

17th September **11th October** **19th October** **25th October** **2nd November** **6th November**

Insularity – the enemy of safety.

by Dai Whittingham, Editor of FOCUS

The legal environment

An eminent member of the legal profession speaking at a recent safety seminar in London observed that regulatory bodies were now communicating with each other not only across national boundaries but also across industrial domain. Prosecutions were being successfully pursued for failures to implement lessons arising from accidents elsewhere even when the circumstances were apparently wholly unconnected but where the failure mechanisms were not. For example, courts may decide that an aviation safety manager ought reasonably to have known that the risk management system he used unsuccessfully was identical to one that also failed dismally in, say, an off-shore oil rig disaster. Perhaps the simplest example of this cross-domain reach can be found in the UK's Health and Safety legislation, where many of the blanket provisions under which we operate – such as the requirement to protect employees from hearing damage – are applicable to all industrial sectors but have their origin in a single legal precedent.

The implication for those of us involved in aviation safety is that we have to become more aware of events in the wider safety community. And the second-order analysis suggests that the old mantra of 'safety is everyone's business' can no longer be derided as a dated cliché. It does not matter who brings the information or observation to the table, what matters is that it reaches the table in the first place and, secondly, that you do something with it. Put another way, a more open and collaborative approach to safety is required in today's environment.

Confidentiality

In terms of an open approach, there is a fine line between proper confidentiality and a genuinely just and honest safety culture. Too little confidentiality discourages candid reporting, as individuals will naturally be concerned about reputation and career implications where mistakes have been made. On the other hand, too much confidentiality risks over-protecting those who would benefit from formal guidance or additional training; more crucially, it also risks stifling the flow of information so that people are denied the opportunity to learn from the experience of others. It is always worth thinking about the level of protection afforded to information.

Who does safety?

There has always been a sense that only an aviator can really know about aviation safety – if you haven't 'been there', how can you understand what happens in the air? Safety of course doesn't start in the air, the process should be happening well before anyone gets airborne, but there is a large grain of truth in the perception. Unfortunately, there are other grains in the mix as well. The humorously cynical observation that: "A man may be a fool and not know it, but not if he's married..." is also very relevant. Unless you are remarkably self-aware as an individual, we are not good at recognising our own shortcomings until they are pointed out to us. Similarly, our interpretation of any given scenario may be remarkably different from another person's. The clear inference here is that one man's (or woman's) view of safety is not enough if you want to flush out the latent failures.

Extending that argument, the notion that your own safety department can operate in isolation not only smacks of institutional arrogance, it also fails to recognise the fact that we all occasionally benefit from a fresh pair of eyes over our business and, most importantly, that a key piece of your safety jigsaw might be lying un-noticed on somebody else's table. In such circumstances, insularity operates as a direct hindrance to effective safety management.

Also implicit in the above is the understanding that you do not need to be a pilot to play a major role in aviation safety management. (That is not to say that there need be no flight deck involvement, far from it.) Some years ago, a colleague appointed a young non-aviator as his FSO, to predictable howls of derision and protest from the aircrew fraternity. The young man proved to be a highly effective FSO, far more so than his aviator predecessor. He tackled the job with enthusiasm and energy and, from the outset, approached tasks with a refreshing openness and acceptance that he did not have all the facts. In so doing, he brought a hugely valuable weapon to bear, namely a willingness to challenge the status quo rather than just accept it. He asked questions!

Wild cards

This brings us to the concept of the wild card. When you are examining or reviewing processes, especially when they are complex and specialist, it can be extremely useful to have a non-specialist as part of your team. A process mapping exercise of the sort found in a Lean or 6-sigma analysis is hard work – we do not often sit down and try to document every step or touch-point in routine events such as an aircraft despatch – and as a result those involved do not always ask the right questions or look beyond the obvious. Some companies already use non-specialists for contextual interviews as part of the FDM process. You need someone who will ask why action A/B/C is done, or why it is done in the fashion prescribed. If it prompts the "Yes, why do we do that?" question in return, your nonspecialist has been well-worth the investment. And occasionally, such non-specialist questioning in a safety investigation produces a nugget that allows you to nip a latent problem in the bud, which is, after all, what we are here for. So if you find anyone questioning whether you can afford to use non-specialists, or whether you can afford to be part of a wider safety organisation, the real question you should be asking is: "Can we afford not to?"

TOP TEN TIPS FOR PILOTS

THUNDER STORMS

WHAT PILOTS **SHOULD KNOW**

- Controllers cannot see thunderstorm cells on their radars.
- Requests for specific weather avoidance headings/levels may result in you going outside of controlled airspace. Be familiar with ATSOCAS as the ATC service you will receive will change and you will become responsible for your own separation.
- A requested routeing may infringe the airspace of other controllers and co-ordination will need to be carried out before the routeing can be approved.
- Where multiple aircraft are weather avoiding, it may be necessary to separate all aircraft in the sector by level.
- Other aircraft which are avoiding weather may affect your routeing.
- Controllers can pass onto pilots information relating to thunderstorms gathered from Met feeds (not to the radar) and pilot reports.
- RTF workload will increase as weather avoidance causes an increase in calls and requests from pilots.
- The location of weather cells is dynamic; reduced landing rates, due to aircraft unable to land at airfields, will increase enroute holding.
- Sector capacity may be reduced to allow for increased separation requirements and loss of holding areas.
- If you turn to avoid weather without a clearance from ATC, you may no longer have separation from aircraft around you.

SPA
SAFETY PARTNERSHIP AGREEMENT

For further information on the SPA (Safety Partnership Agreement) please visit www.customer.nats.co.uk

TOP TEN TIPS FOR PILOTS

THUNDERSTORMS

WHAT PILOTS **CAN DO**

- Tell controllers as soon as you know you will need to avoid a thunderstorm.
- Be precise when giving information on location and size of thunderstorm cells.
- Where possible, be flexible on what clearances you can accept - you may prefer to turn left, but can you turn right and still avoid the weather.
- When requesting a heading, advise the controller how long you anticipate it will be before you are clear of the weather.
- Advise ATC when clear of weather, but remain on the last assigned heading unless otherwise instructed. (The weather avoidance heading may now be being used tactically to separate you from other aircraft.)
- Be proactive; think about what you can do, as well as what you can't.
- Keep RTF transmissions to a minimum.
- If you can't follow the SID tell ATC **before** getting airborne.
- Give the controller as much warning as possible of diversion intentions.
- If you are unsure, always check.

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Training the Next Generation

Fiona Greenyer looks at the ways in which cabin crew training is evolving to engage the 'net' generation.

Above: TFC believes that realistic hands-on training increases knowledge retention. Image credit: TFC Simulatoren und Technik GmbH.

The majority of new entrants into cabin crew training are from the so-called 'Generation Y', defined as those born after 1982.

These young people have grown up in an environment in which computers, the internet and virtual reality are the norm. They have different skills, are motivated by different issues and have different ways of learning from more traditional "chalk and talk" methods. The aviation community is now developing new ways to recruit, educate, train and retain the next generation of aviation professionals.

Countless advancements have occurred in the evolution of training the next generation of cabin crew. From online pre-qualification training to interactive recurrent training, airlines have been looking for new ways to save money but also keep relevant to the way their students learn.

The advent and adoption of new ways of doing business have seen aviation professionals using a multitude of different devices as learning tools. The advantages of such devices are massive, however as Ivan Noël, president of Inflight Institute.com pointed out that if implemented incorrectly the results can be disastrous. If the developed content cannot be viewed by all devices at any time, the litmus test of the learning system has failed.

Blended Learning

InflightInstitute.com believes that a blended approach is paramount in teaching the 'net' generation of learners. This generation, and the ones that will follow it, has a 'hyper-texting' mindset, they are able to multi-task with various devices and have a need for instant gratification and knowledge. They love technology and want to use it. A blend of self-paced learning, classroom learning and hands-on learning achieves the best results for the "net" generation of learners according to Noel. He believes that this fine balance between the technological and human elements are the biggest challenge to the successful delivery of online-based training.

German company TFC offers computer-based training to its cabin crew students, but are convinced that it is important to emphasise the human performance aspect of training as well. This means that the company has transferred the theoretical training from the classrooms into the cabin simulators where they create the most realistic training situation available. Alongside the CBT, TFC has found that using the realistic practical training helps the flight attendants retain more information. Having experienced this kind of training, attendees leave the training session having gained the confidence to handle emergency situations, and furthermore, this integral training conveys team building. TFC has found that younger flight attendants feel more confident in using new technology for training, but in order to retain information, the practical training has shown evident advantages.

Alongside the CBT, TFC has found that using the realistic practical training helps the flight attendants retain more information. Having experienced this kind of training, attendees leave the training session having gained the confidence to handle emergency situations, and furthermore, this integral training conveys team building. TFC has found that younger flight attendants feel more confident in using new technology for training, but in order to retain information, the practical training has shown evident advantages.

Cabin Aviation Training of Sweden AB was started in 2005, and since the beginning of 2011 has had approval from the Swedish Transport Agency for a self-sponsored Cabin Initial Safety Training course according to EU-OPS 1.1005. The course is two weeks long and covers subjects such as general aviation knowledge, first aid, service, crew resource management, fire and smoke training, water survival and discipline and responsibilities. Ann-Charlott Strandberg, Head of Training at CAT of Sweden commented that the methods of teaching that they use have had to be updated and developed to be relevant to the students they are teaching today. The vast majority of CAT of Sweden's students are aged between 21 and 35 years old, and old styles of teaching and learning are not an effective way to teach them new skills and knowledge.

Strandberg noted that students used to be passive, sitting in a classroom looking at PowerPoint slides. They found that this was not an effective method of teaching so they banned PowerPoint!

The internet is a powerful tool for learning, but Strandberg was careful to point out that her instructors take the time to make the students aware of what is the best content to use from the internet. "This is the downside of the web" she said.

Noël also made this point. "We will release some of our video productions to YouTube for information and promotion, however we never use YouTube as reference links within our programs. Airlines must be very cautious of including such uncontrollable means of media within their learning system."

As instructors, Strandberg noted that they have to make time within a class for online searches which can be demanding for the instructors who have to be open minded about this way of learning, as they themselves are from a completely different generation.

In order to achieve the greatest saturation of knowledge, there must be a great focus on the end user.

Wolfgang Jabornik, Head of Training at Flight Attendant Safety Training GmbH told CAT his company has noticed three big changes in teaching the new generation of cabin crew. New studies prove that over half of new cabin crew entrants expect to leave their employer within two years, and 40% are expected to leave within one year. Learning tools have to be adapted to the interests of this new generation of cabin crew. "Trial and error is the keyword of this generation that is used to playing computer games" he explained. "Their attention span is short, learning tools are consumed repeatedly and less intensively, more often and for a short period of time. They are used to the availability of information 24 hours a day, seven days a week."

FAST offers a pre-employment course which is 100% online and worth two days of an airline ground course. The company also offers an initial safety training course which consists of about 80% e-learning and the rest as practical training. The course takes 12 days to complete and covers the generic aspects of safety training. The advantages for airlines employing successful students from this course means that they have 12 less days of training to complete with their new crew. The ground course can be carried out at the students' own pace and in their own time. They are not on the airline's payroll for the time they complete the course, and for airlines recruiting these students it means that they have 12 days less of training to carry out with their new crew.

Airline View

Swedish airline Novair uses a combination of elearning and practical training. Last autumn they examined 36 brand new cabin crew and the majority were 21 to 26 years old. Anna Mellberg Karlsson, chief cabin safety instructor at Novair said, "These new recruits were online most of the time with smartphones, iPads etc., but to our surprise they were not so eager to go online for course related issues."

The airline recently got rid of all books in favour of putting the Cabin Crew Manual on the company information portal, but found that the students preferred the Manual in paper format. "Luckily 40 copies were saved for training purposes!" said Karlsson.

"The only course we have as CBT today is Dangerous Goods training. We are looking into different courses in CBT to complement classroom training," explained Karlsson. "We are planning for the crew to perform the tests online so we don't have to take time for this during precious course time."

The challenge for Novair is to get the 'oldies', cabin crew aged 37 years and up, to get into and understand this new world of technology. However, course feedback revealed that the students wanted more practical training.

This type of training is constantly evolving, with social media becoming more widely used as a tool for communication. FAST uses Twitter as a means for students to ask questions, and CAT of Sweden uses Facebook to interact with their students. The 'net' generation requires a specific blend of learning styles and tools to achieve the best results for all parties involved.

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The Pilot Lifestyle Investigated

by Dr Simon Bennett

Concerned to develop a fuller understanding of pilot fatigue, stress and other factors, in 2010 the British Air Line Pilots' Association (BALPA) funded Dr Simon Bennett of the University of Leicester's Civil Safety and Security Unit (CSSU) to investigate the pilot lifestyle. BALPA intended to use the study to inform the European Aviation Safety Agency's (EASA's) deliberations on a new Europe-wide Flight Time Limitation (FTL) scheme.

While there has been some research into the pilot lifestyle over the years (see Chiles (2011) for a partial summary) the BALPA-funded study was notable for its scale. Three research instruments were used: a Sleep Log (SLOG), an on-line questionnaire and interviews. Kept for three weeks, SLOGs ranged in size from 2,000 to 9,000 words. They recorded both work and home activities (please see example below). The questionnaire contained 54 questions and produced statistical data and extensive written evidence. The interviews, which could last several hours, were tape-recorded then transcribed. By the end of the research period (Summer 2010 – Spring 2011) over 130 SLOGs and 433 questionnaires had been analysed. The end product was a pilot's-eye view of the aviation industry. Although the author sorted and interpreted the data, the dominant voice in *The Pilot Lifestyle: a sociological study of the commercial pilot's work and home life* is that of the pilot. The major themes to emerge from the SLOGs, questionnaires and interviews are described below.

1 Sleep debt

The report's author assumed that one hour of sleep generates about two hours of productive wakefulness (sleep credit). When a pilot has used up all her/his sleep credit, s/he moves into sleep debt. There are cognitive impacts: reasoning slows; reaction times slow. The data showed that both long-haul and short-haul pilots accumulate sleep-debt. One low-cost pilot flew an approach into a U.K. airport with a sleep debt of 16 hours. Over 86% of those who completed the on-line questionnaire ('respondents') said they had flown a sector when fatigued. Over 92% of respondents said they had driven home in a state of fatigue. Over 84% said they had failed to get adequate rest at home. Factors included telephone calls (cited by 23% of those who said they had failed to get adequate rest), extraneous noise (23%), household noise (24%), work-related stress (27%), household duties (43%) and family-related stress (53%). Regarding the issue of family-related stress, Chiles (2011) notes: "Fatigue and mental preoccupation [are] the most frequent manifestation of home-based stressors .... Exhaustion is a common response to the stress of an argument ... ".

2 Extended periods of wakefulness on a duty day

Over 86% of respondents said they had experienced a period of continuous wakefulness exceeding 18 hours on a duty day. Of these, over 20% said they had experienced a period of continuous wakefulness equal to or exceeding 28 hours. One of the pilots in this latter group said he felt "'Drunk' with tiredness. I was unable to carry out any task that required any form of mental agility." Another said he felt "Punch drunk. Utterly exhausted. Incapacitated. I checked straight into a hotel and didn't even drive home." A study by the U.S. National Transportation Safety Board found that Captains who had been awake more than 12 hours made significantly more errors than those who had been awake less than 12 hours. One respondent wrote: "On returning to LGW I would basically be asleep or nodding off between the Isle of Wight and 1,000ft on approach. After two days 'off' (read sleeping and ironing) I would do 5 days on, each of approximately 12 duty hours. With my drive to work, and a 30-minute bus drive from the car park to the crew centre, I would be out of my house for at least 15 hours a day."

3 Roster instability

Most pilots understood that rosters could be changed at short notice. To anticipate the worst-case scenario most went to bed when they could. Few, however, were able to 'sleep-to-order', resulting in long periods of wakefulness (see above) and sleep debt. It was concluded that roster instability (volatility) creates a latent risk. Crewing and rostering officers are either assuming that pilots can sleep-to-order, or are ignoring evidence that pilots can't sleep-to-order. By overturning pilots' plans for rest and recreation, roster-changes upset the work-life balance. Gambles, Lewis and Rapoport (2006) claim: "[P]aid work has become increasingly demanding and invasive in people's lives." Over 73% of respondents said they had felt unduly stressed at work. Nearly 80% of respondents said they had felt unduly stressed at home. Over 40% of respondents said that relationships with partners/offspring had affected their working life. Nearly 20% said they had sought advice/help for a domestic relationship issue. Stress affects performance: "The primary effect of home stress on work is in the mental or cognitive consequences: recurring thoughts during periods of low workload, decreased concentration and a tendency not to listen" (Sloan and Cooper, 1987). Young (2008) notes: "Even for the most expert or skilled performers, it is likely that cognitive processes, at one time or another, will be affected by life-stress in a way that impairs performance."

4 CAP371 as a target, not a back-up

The CAP371 limit is 900 flying hours per annum. This does not include flight preparation, turn-around tasks, end-of-duty tasks, positioning, office work, etc. It was never intended that the 900 hour limit should be routinely achieved. Many pilots claimed that their airline saw CAP371 as a target. A typical comment was: "The Captain is on leave tomorrow. He has done 893 flying hours in the past 365 days. He was utterly knackered [exhausted] and I felt I needed to be above my game to compensate." Over 13% of respondents said they had refused a duty in the past 12 months because of perceived fatigue. Two factors encouraged pilots to work while fatigued: feelings of obligation to colleagues and passengers, and a 'can-do' attitude. From a safety perspective camaraderie is a good and bad thing. Good, because it underwrites CRM. Bad, because it causes flight crew to ignore fatigue.

5 A pilot diaspora

Aviation is a volatile industry. Obliged to 'follow the work' pilots could find themselves commuting long distances. Over 30% of respondents took between 60 and 120 minutes to commute. Nearly 23% of respondents lived between 51-100 miles from base (meaning a car journey of at least one hour). Nearly 7% of respondents lived between 101-150 miles from base. Nearly 30% of respondents used temporary accommodation. One said: "[I use temporary accommodation] because I can't commute 2,000 km on a daily basis." Over 83% confirmed that their airline would not subsidise hotel accommodation for fatigued crew returning to base.

6 The FRMS 'trap'

A fatigue risk management system (FRMS) enables operators to develop an FTL that balances the rest and recreational needs of flight crew with the company's operational requirements. Operators use qualitative data (like fatigue reports) and quantitative data (like Actiwatch print-outs) to run their FRMS. Data is the lifeblood of the system. Without data rosters cannot be validated. A non-validated roster creates a risk (because, unbeknown to managers, the roster may induce pilot fatigue). Pilots won't file fatigue reports a) if they believe they will be ignored or b) if they fear victimisation. A FRMS cannot function properly without a just-culture and pilot buy-in. There was some evidence of pilots reporting sick when they were, in fact, fatigued. 'Masking' undermines a FRMS (because it inhibits feedback).

7 Industrial relations and trust

The data suggested a deterioration in industrial relations, both between pilots and management and between pilots and cabin crew. Several pilots talked about a 'bonus culture' amongst managers. One wrote: "[The industry] is in a gradual state of decline and managed by short-term bonus-grabbing people." Another wrote: "Directors are bonus-driven, and don't care if the airline exists in five years time. The contempt shown to the profession by managers says it all." Over 73% of pilots said their relationship with cabin crew had changed over time. Nearly 16% of respondents described their relationship with cabin crew when on duty as 'poor'.

8 Reporting/just culture?

A reporting/just culture is one of the building blocks of a safe airline. If pilots think they might be exposed and/or victimised they will be less inclined to report slips and errors: "If he/she believes their identity can not or will not be protected, or that their report of a safety problem will affect their relationships with other co-workers, then even large levels of motivation stemming from possible benefits of creating a change are at risk of being negated" (Harper and Helmreich, 2003). Non-reporting prevents organisational learning (learning from experience). Some pilots questioned whether their airline maintained a just culture. One said: "There is little or no protection for us. There is a culture of 'bullying' by the management ('How dare you be tired'). Another said: "I have reported fairly innocent mistakes and it has been blown out of all proportion." Turner (1978) argued that accidents, far from being bolts-from-the-blue, have a long and increasingly visible genesis (the 'incubation period'). Pilots' non-reporting of error and fatigue incubates incident and accident. Finally, there may be a disconnect between an airline's recorded safety commitments (noted, for example, in the Safety Case, which recognises the need for a reporting/just culture and carries the CEO's imprimatur) and reality. Disconnects between rhetoric and reality represent latent errors/resident pathogens.

9 Control loci – a source of frustration?

Flight operations are characterised by multiple centres of control. Pilots shoulder great responsibility. They are responsible for the safety of their passengers, aircraft and crew and, to some degree, for the economic performance of the airline. Pilots' authority is (largely) situated on the flight-deck. It is bounded. Most have no control over their rosters (fatiguing rosters may impact a flight crew's ability to operate safely and efficiently). When it comes to roster planning, the locus of control rests firmly with back-office staff, most of whom have no first-hand knowledge of the lived reality of flight operations. Such 'remote control' is problematic for two reasons. First, because it ignores a useful source of information on roster planning – the pilots. Harper and Helmreich (2003) speak to the potential benefits of exploiting pilots' intimate knowledge of flight operations: "[T]he strength in reporting systems stems from using the operator [pilot] as the expert in the organization and that the operator is not only a powerful determinant in compliance with safety practices but privy to information of how to best manage regularly occurring safety issues." The potential performance gains from tapping local or situated knowledge are discussed by academics like Professor Brian Wynne (1996) of Lancaster University. Secondly, because some pilots experience remote control as an affront. ICAO sees preferential rostering as a means of involving pilots in roster planning. Some pilots are 'day people' while others are 'night people'. Preferential rostering provides a way of shifting the locus of control more towards flight crew. It addresses the physiological capacities of individual pilots. (Of course, individuation costs money. It is cheaper for rostering departments to stereotype pilots than to acknowledge difference). Because preferential rostering involves pilots in the management of fatigue (and, to some degree, of the company) it breaks down the 'us-and-them' mentality that has become so much a feature of commercial aviation in recent years.

10 Pilots and business people?

It has been suggested that many pilots have second jobs and that this creates a fatigue problem. Just over 3% of respondents said they ran a business from home. (Just over 7% confirmed that another household member ran a business from home). Of those pilots who ran a business from home, 71.5% devoted no more than 10 hours to it in a typical non-flying week. It is incorrect to claim that many pilots have second jobs.

11 Flight preparation as a stressor?

Over 28% of respondents felt they did not have enough resources to adequately prepare for their duty. Problems included lack of time and information technology issues. At one

London airport it took pilots from a low-cost airline at least one hour to commute from their designated car-park to the crew room. From a flight-safety perspective it is best to minimise pilots' exposure to stressors.

12 Security checks as a stressor?

Over 95% of respondents said that current security measures were 'excessive'. No-one said they were too lax. Over three quarters of respondents were of the opinion that passing through security had compromised flight safety.

13 Stress, fatigue, catharsis and closure

If stressed or fatigued most said they would confide in their partner. Few said they would confide in a manager. The following table ranks sources of advice and help in relation to their popularity amongst pilots (most popular at the top):

- Partner
- Trusted colleague
- Trusted non-work friend
- Family G.P.
- Fleet Manager
- Aviation Medical Examiner
- Other (for example, a psychologist)
- Chief Pilot
- Crewing Officer
- Offspring
- Rostering Manager
- Operations Director
- Personnel Director
- Chief Executive Officer

A typical comment was: "I could not possibly contemplate talking to anyone in authority .... I have utterly no confidence that the matter would be dealt with properly. My poor wife bears the brunt of things. Her support is sometimes all that keeps me going."

Conclusions

Some pilots faced long drives to work. Driving to and from work is tiring and stressful. It means getting up earlier and getting to bed later. Tired and stressed pilots are more error-prone. Pilot morale is low. Only 19.2% of pilots said they would recommend a career in aviation to their offspring.

There were trust issues, both between pilots and managers, and pilots and cabin crew. Few pilots were prepared to confide in management, preferring to confide in a partner or keep their counsel. The non-discussion of personal issues (stress, for example) may lead to more serious problems (poor sleep, contributing to under-performance on the line). There is a nexus between trust and safety. Trust is fragile. Even the faintest perception of betrayal can erode confidence in management, undermine industrial relations and weaken an airline's reporting culture (thereby inhibiting organisational learning).

At some FRMS-compliant airlines there seemed to be a disconnect between safety rhetoric and safety reality. Some pilots masked their fatigue. Incapable or unwilling to quantify masking, regulators approved dysfunctional FRMS systems. A more rigorous oversight is required. Regulators need to look beyond compliance. They need to understand an airline's culture – how its employees actually behave – before they judge its safety. Governments need to ask whether the 'revolving-door' movement of personnel between commercial and regulatory appointments compromises oversight. Does the revolving-door create conflicts of interest? Or does it ensure that knowledge is spread throughout the industry, to the benefit of all? Cullen's (1990) observations on the Piper Alpha disaster are apposite: "It is essential to create a ... culture in which safety is understood to be, and is accepted as, the number one priority."

Finally, the data suggested that pilots' physical and psychological capacities vary. It is reasonable to conclude that there is no singular pilot model. Rather, there are models. It is suggested that, as far as is reasonably practicable, regulators and airlines acknowledge human variability in FTLs and rosters. From a safety perspective the case for Fatigue Risk Management Systems, preferential rostering and other locally-owned risk-management tools is watertight – with the proviso that participating airlines cultivate a reporting/just culture.

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Appendix

SLEEP/ACTIVITY LOG

DAY	DATE (DD/MM)	DIARY (please record as much information as you can; all times in Zulu)
1	14/09	Stand-by day. Woke at about 08:00z. Slept well considering the late supper. Crewing called. Now rostered to operate two sectors. Captain reported sick. Left for base at 11:00z. Journey uneventful. Arrived at 12:00, well before 12:30 report time. Plenty of time to talk with, and brief crew. Had flown with F.O. and SCCM before. Uneventful day. EMA-CGN-EMA. Achieved turnaround target. Landed back on schedule. Set off at 18:15. Home by 19:00. Plenty of energy, so went out for a curry with all the trimmings. Saves cooking. Got to bed later than usual. Watched some T.V. in bed. Husband snoring. Fell asleep at around 00:45. Briefly woken twice by husband's snoring. Gave him a dig in the ribs. Alcohol makes him snore.
2	15/09	Leave day. Got up early to play golf (had to take what they had as club very busy). Had lunch at the club. Healthy salad. Got home mid-afternoon. Feeling fit, if a little tired. Promised husband I'd mow lawns, so no choice. Mowed lawns. Ate pizza supper together at about 20:00z. Felt really sleepy after meal, so went to bed early. Fell asleep straight away.
3	16/09	Woke at about 08:30z. Felt well rested after an uninterrupted sleep. Spent this leave day pottering around house. Had a nap after lunch. Went for a run. Managed about three miles. Felt good afterwards. Husband made me fish supper, so I washed up. He says there may be redundancies at his engineering company. Talked through our options if the worst happened. My mother called. She says Dad is not so good. He may have to go back into hospital.
4	17/09	Woke earlier than intended. Worried about husband and Dad? Only two sectors today, so things should be O.K. Ate a substantial fried breakfast. Slight indigestion. Set off for work at 08:30z to make my 10:15 report. Heavy traffic and delays on M1 due accident, so arrived slightly late for report (10:25). Rushed the briefing a bit. Had not flown with the F.O. or SCCM before. Operating EMA-VCE-EMA. Flight time around 2hrs 20mins each way. Medical emergency on EMA-VCE sector (elderly passenger) necessitating medical team on arrival. Turnaround extended to 90 minutes. VCE-EMA sector uneventful. We all felt tired on arrival at EMA, though. Medical emergency tested the crew. M1 in better shape. But arrived home with thumping headache. Two Aspirin. Husband made supper. Went to bed at about 21:30, but did not fall asleep until 22:30.
5	18/09	Fitful night's sleep. Got up at one point to make a cup of cocoa. Watched News 24 until I felt sleepy again. Woke at about 07:30 feeling as though I'd been hit by a train. Drank two strong cups of Nescafe. No breakfast. Four sectors today. Another unfamiliar F.O. But at least I know the SCCM. This should be interesting. Made 10:15z report in plenty of time. Crew change, so I got an F.O. I knew, but a SCCM I did not know. It took us 20 minutes to get through crew channel security. We had to queue behind other crews. Bags open, shoes off, the lot. I even had to remove my belt. Checkers more supercilious than usual. Tiresome. Not the best start to a long day. Tech fault and trainee Dispatcher delayed departure by 40 minutes. Operating EMA-VCE-EMA-CGN-EMA. SCCM had to issue warning to party somewhat the worse for wear with drink. I issued a warning in flight. Seemed to do the trick. Drunken PAX apologised to SCCM for earlier misbehaviour. A laboured turnaround. Fuel bowser late. PAX late. Dispatcher not on the ball. On the ground for 55 minutes. My energy levels dropping. Ate crew meal on VCE-EMA sector. Gave me a boost. Felt more alert. Probably drank too many cups of coffee. But what's the alternative? Crisp turnaround at EMA (knew the Dispatcher. Old hand. Competent). Small load to CGN. More in-flight coffee. Ate a banana to keep my energy levels up. Another crisp turnaround at CGN due to small load and alert Dispatcher. Made up some time on final leg. Straight in to EMA. No delays (unlike LGW and LHR). All things considered, a typical day flying low-cost. Reflected on my condition at engine shut-down: tired (eyes burning), irritable (had to 'hold-it-down'), hungry and in need of a shower. Same sectors tomorrow. Different crew. Roll on.
6		... etc.

Dr Simon Bennett – September 2011

The author

Dr Simon Bennett, Director of the University of Leicester's Civil Safety and Security Unit (CSSU), has a PhD in the Sociology of Scientific Knowledge. He has consulted to the airline industry for over a decade. He uses action research (observation, survey and interview) to develop/test theory and improve safety. He has occupied the jump-seat on many hundreds of sectors. (Photograph shows author at work)

Forecasting Thunderstorms

An understanding of convection provides clues to these atmospheric monsters.

by Ed Brotak

Convection remains a serious problem for the aviation community. Severe turbulence above the ground and strong winds with wind shear near the surface are amongst the hazards caused by convective acitivity, which plays a role in many aircraft accidents each year.

Moreover, the massive hailstorm at Dallas–Fort Worth (Texas, U.S.) International Airport in April demonstrated how convection can seriously disrupt flight operations. Hundreds of flight delays and cancellations occurred, and damage to aircraft on the ground was extensive.

Meteorologists must know how convection operates in order to forecast it. They must make a model of the atmosphere, and even of the potential thunderstorm itself, to predict the weather that may be generated. The aviation industry would benefit from a better understanding of the workings of convection.

A simple key to understanding convection is to know that warm air rises and cold air sinks. More precisely, warm air is less dense and therefore buoyant (think of a hot air balloon). Cold air is denser and sinks (e.g., cold air drainage into a valley at night). The terms *warm* and *cold* are relative. A balloon with an inside air temperature of 32 degrees F (0 degrees C) still will rise if the outside air temperature is minus 40 degrees F (minus 40 degrees C). Similarly, convection can occur with temperatures below freezing.

Lapse Rate

So, to determine if air is going to rise, sink or remain where it is, we need to know the temperature of the "inside air" (inside the balloon or inside a cloud) and the temperature of the air outside. We also need to know the *lapse rate* — that is, the change in temperature with height. Outside air temperatures are measured at least twice a day — typically at 0000 and 1200 Greenwich Mean Time (GMT) — from dozens of sites across the United States and hundreds of other stations around the world. Balloon-borne instrument packs, called *radiosondes*, are launched to obtain data on temperature, moisture, pressure and winds up to 100,000 ft.

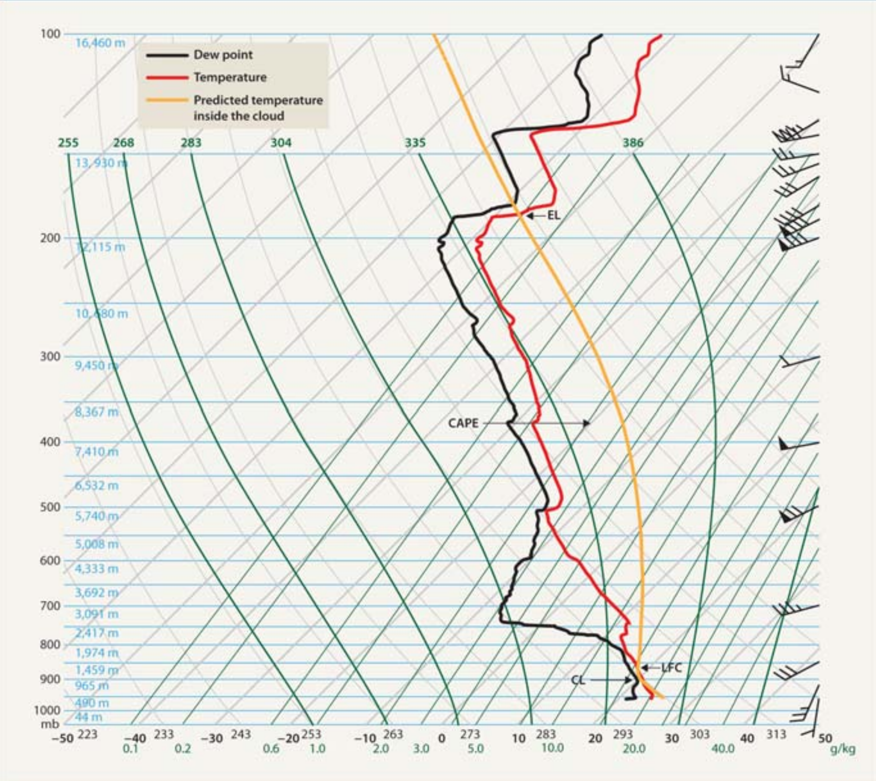
Forecasters then have to determine the inside air temperature so that comparisons can be made.

Starting with the simple case of *dry convection* (no condensation or cloud), we know that air expands as it rises, and the expansion results in cooling. Using the basic laws of physics, we can derive the rate at which dry air should cool when lifted. This is called the *dry adiabatic lapse rate* ("adiabatic" refers to the expansion effect in this case), and the value is 5.5 degrees F per 1,000 ft (10 degrees C per 1,000 m). If the actual measured lapse rate is greater than this, then the parcel of air would be warmer than the environment and would continue to rise on its own. This is an unstable situation. We find lapse rates like this fairly close to the ground, usually on days with abundant sunshine. Columns of rising air, the *thermals* that glider pilots use, are common in this situation. But lapse rates of this magnitude are unusual at higher altitudes, and this type of convection is not "deep" (i.e., not extensive).

Dynamic and Dangerous

When water is added to the mix, the situation becomes more dynamic and potentially dangerous. Convective clouds, the cumulus cloud family, always provide some turbulence,

Sounding at Springfield, Missouri, U.S., May 23, 2011



CL = condensation level LFC = level of free convection EL = equilibrium level CAPE = covection available potential energy
Source: Ed Brotak, from the Plymouth Weather Centre

Figure 1

which can range from a few bumps in "fair weather cumulus" to the potent updrafts and downdrafts in cumulonimbus thunderheads that can rip an airplane apart. On the plus side, the condensed water makes the air currents visible as clouds. Imagine if a pilot could not see currents of air rising and sinking at speeds that can exceed 100 mph (161 kph).

Besides making convective clouds and the various forms of precipitation associated with them, water plays a critical role in convective development. When water vapor condenses, heat is released. Technically, when water molecules go from the energetic gas form (vapor) to the more confined liquid form (water) or solid form (ice), energy is released. This *latent heat release* raises the temperature of the air within the cloud. If the parcel of air continues to rise, it will cool at a slower rate — the *moist adiabatic lapse rate*: 3 degrees F per 1,000 ft (5 degrees C per 1,000 m). With the parcel cooling at a slower rate, it is still likely to be warmer than the surrounding air. Therefore, moist air is potentially more unstable. This process does not require a lot of moisture. Convective lifting is so strong, a moist layer near the surface, perhaps only a few thousand feet thick, is all that is needed to support convection. Interestingly, dry air aloft helps promote strong convection, whereas a deep moist layer aloft often produces heavy rain but less wind and turbulence.

So, the two primary factors that meteorologists look at to forecast convection are the lapse rate and low-level moisture. To quantify the forecasts, meteorologists have developed a number of indices that incorporate these two factors. The *Lifted Index*, the *Showalter Index*, the *Total-Totals Index* and the *K Index* can be calculated for each situation, and the numerical values determined from the calculations can be compared to standard values for the occurrence of convection or severe convection. All of these indices were developed prior to the advent of computer technology. Although they are still used today, computer-generated products are much better.

Sounding the Atmosphere

The main tool meteorologists use to forecast convection is the *sounding*, a vertical profile of the atmosphere. A standard plotted sounding consists of two lines showing temperature and dew point, with wind data usually given on the side of the plot. Forecasters can use actual morning soundings and allow for expected changes by afternoon or, with today's sophisticated numerical models, use computer-generated forecast soundings for later in the day.

For an example, Figure 1 is the 0000 GMT 23 May 2011 sounding for Springfield (Missouri, U.S.) Municipal Airport. This sounding represents the atmospheric conditions that produced the thunderstorm that spawned the tornado that devastated nearby Joplin, Missouri. The red line is the actual temperature trace, and the black line is the dew point from the surface to 16,460 m (54,000 ft). From the surface temperature and dew point, we can calculate the *condensation level* (CL). For this calculation, we simulate the lifting of this surface air by using the dry adiabatic lapse rate to determine the height at which the air would be cooled sufficiently that its temperature equals the dew point. In this case, the condensation level is 840 m (2,750 ft). The condensation level typically marks the base of the cloud. Below this level, where the parcel of air is cooler, energy or lift must be provided for condensation to occur. The energy required is called *convective inhibition* (CINH). If this value is large (e.g., 200 or more) or there is nothing to help the parcel rise, there will be no convection. In this example, the CINH is a minimal value of 3.

The yellow line is the predicted temperature of the air inside the cloud. The red and yellow lines intersect initially at 1,300 m (4,200 ft). This is called the *level of free convection* (LFC). Above this level, the air inside the cloud is warmer than the air outside and will rise on its own. This becomes the updraft, the core of the storm. The lines cross again up at 13,000 m (42,000 ft), at what is known as the *equilibrium level* (EL). Above this level, the air in the cloud is colder than the environment. This often corresponds with the cirrus anvil of the thunderstorm cloud.

The updraft does not stop at the equilibrium level because the air in the updraft has accumulated upward momentum, or energy. This energy is proportional to the area on the sounding between the actual temperature trace and the parcel temperature trace — that is, where the parcel is warmer than the environment between the level of free convection and the equilibrium level. Meteorologists call this the *convective available potential energy* (CAPE). The CAPE indicates the potential strength of the updraft. A CAPE of 500 usually would support only weak convection, but the CAPE value here, 3,692, is indicative of severe thunderstorms. This excess energy propels the actual top of the cloud well above the anvil in what is referred to as an *overshooting top*. Viewed from above, the top of a thunderstorm looks like a boiling cauldron. The air in the updraft surges upward and then sinks back down in bursts. The actual height is a function of the CAPE. In this case, the predicted cloud top was an impressive 17,000 m (57,000 ft). With the tropopause height of 13,930 m (46,000 ft), this storm extended well into the stratosphere.

So far, we have discussed only the updraft of a thunderstorm. In terms of development, it is the updraft that produces the storm. But turbulence also consists of downdrafts, which can produce strong winds and wind shear at the ground. Initially, downdrafts are started as rain begins to fall from the cloud, pulling some air down with it. Evaporative cooling lowers the temperature of this descending air, accelerating the downdraft even more. Dry air aloft, which would intensify the cooling effect, is one thing meteorologists look for in predicting strong downdrafts. Large thunderstorms and thunderstorm complexes often develop complex circulations. Outside air can be pulled into this circulation and produce a mid-level (10,000 ft or 3,000 m) inflow. This colder, drier air can become a powerful downdraft. Also, this air brings with it momentum gained from the winds aloft. These strong winds can be brought down to the surface by the downdraft.

Convective Triggers

Even if the environment is potentially unstable, something is needed to start or trigger the convection. Typically, parcels of air need a boost to reach the condensation level — something to lift the unsaturated air upward, causing it eventually to cool to the dew point. From there, the latent heat that is released can help the parcels utilize the inherent instability. As mentioned above, strong heating of the surface by the sun in the late spring or summer is a typical convective trigger. If the temperature of the air near the surface warms sufficiently, the *convective temperature* can be reached, and parcels of air will start to rise on their own.

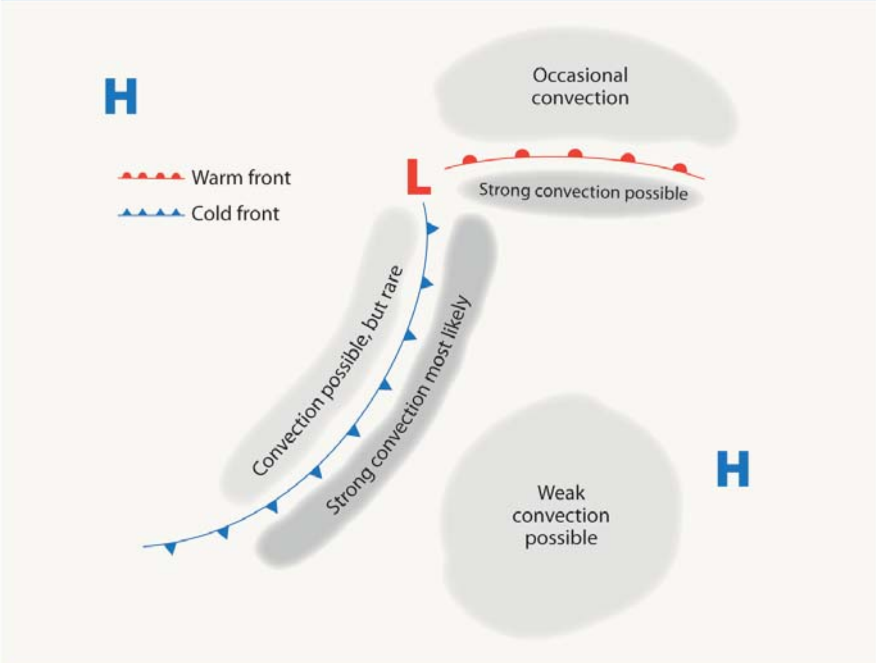
Orographic lifting is another common cause of convection. Winds blowing upslope can lift parcels of air to their condensation level. This is why convection is more prevalent over mountainous terrain. *Convergence* at low levels also can cause convection. When air converges near the ground, it is forced upward. This can happen ahead of a true front, along a gust front or the outflow boundary from previous convection, or beneath various upper-level systems.

The surface weather features shown in Figure 2 can cause typical "air mass" showers and thunderstorms to develop in the warm, humid, southerly flow on the west side of a high pressure area, away from any fronts or lows. Air mass thunderstorms are the result of daytime heating. This convection is not organized and usually is fairly weak. When convection occurs closer to the low and fronts, but still in the warm air, it tends to be more organized and stronger. The convection is aided by divergence aloft with upper-level troughs and the jet stream. This is what meteorologists call *synoptic forcing*. When synoptic forcing is very strong, convection often organizes along lines parallel to the mean wind. These are the familiar squall lines. Often, the convection itself is strong to severe. Beside extreme turbulence aloft, strong winds at the surface are common, and hail is possible. Interestingly, moderate amounts of synoptic forcing and significant instability can combine to produce the strongest thunderstorms: the supercells. This was the case with the Joplin storm.

Rotating Updrafts

Another factor that forecasters examine at low levels is wind shear. When winds veer (turn clockwise) from the surface to several thousand feet, the updraft in a thunderstorm can convert this vertical wind shear into horizontal rotation. Rotating updrafts are associated with the strongest storms and produce the most severe weather, including strong straight-line winds, large hail and even tornadoes. To quantify this, meteorologists calculate the *helicity*, the difference between the winds at different levels. High helicity values (over 300) indicate greater potential for severe storms.

Convection Catalysts



H = high pressure area L = low pressure area
Source: Ed Brotak

Figure 2

On many days, the convection is shallow, resulting in only fair weather cumulus clouds with little vertical development. The air may be too dry, and the clouds literally evaporate; or the atmosphere may be too stable to allow much development. In this situation, meteorologists often say the atmosphere is "capped." Stable lapse rates occur at levels above the effects of surface heating. When the atmosphere is uncapped and unstable, updrafts can soar tens of thousands of feet, producing *cumulus congestus*, or towering cumulus. When the updraft air finally reaches its thermal equilibrium level, it spreads out to form the anvil characteristic of a cumulonimbus cloud, the "thunderstorm cloud." Regardless of whether an anvil top has developed, cumulus clouds of this magnitude pose the greatest risks to pilots.

Edward Brotak, Ph.D., retired in 2007 after 25 years as a professor and program director in the Department of Atmospheric Sciences at the University of North Carolina, Asheville

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