SCHOOL OF AVIATION
Lund University

Human Factors in Aviation - A natural history

Sidney W. A. Dekker

Technical Report 2003-02

Lund University School of Aviation
Address: 260 70 Ljungbyhed, Sweden
Telephone: +46-435-445400
Fax: +46-435-445464
Email: research@tfhs.lu.se

Paper presented at the FAI conference in Linköping, 26 September 2000

There was a time when human factors was still simple. The first pilot who raised his wheels instead of his flaps after landing many years ago (with nasty consequences for the aircraft's belly and propeller) presented a relatively straightforward challenge. If pilots mix up their flap and wheel handles, well, then make different handles. In fact, make not only different handles (different shape, size, location), but *relate* those handles in some obvious way to the function they perform. The flap lever should look (and feel) like a flap; the gear lever should look (and feel) like a little wheel, which they do today. Engineers happy, pilots happy.

Human factors problems did not end with flap and wheel confusions. From the engineer's perspective, pilots seemed to possess an unlimited ability to screw things up. And from the pilots' perspective, cockpits seemed to contain an unlimited number of opportunities for them to screw things up. Many of these error traps could be made to go away. The C-47 transport, for instance, had its mixture knobs on the left, its throttles in the middle and its propeller pitch controls on the right. The C-82 placed propeller on the left and mixture on the right, while the B-25 started with throttle on the left, propeller in the center and ended with mixture on the right. So what about the poor guy transferring across these types during his service career? There they were: sources of confusion—pushed down into his cockpit with only him as last line of defense against the error pitfall they formed. A design fix in the form of standardization (throttle, prop, mixture from left to right) became the answer to this particular problem. Engineers undisturbed, pilots happy.

Many of the earlier human factors lessons apparently *had* to be learned the hard way. The F-111 (affectionately called the "Aardvark") had a sweeping wing design so that it could fly both slowly and fast. "So, how should the control for the wing-sweep work?" you hear the engineers wonder. Well, it was obvious: for forward sweep, move the control forward. For backward sweep, move the control back. A perfectly logical solution. What the control does, the wing does: one-to-one mapping. This is sound human factors, baby. Except..., well, except what? Pilots still screwed up. By now, moving *anything* forward in cockpits (the control stick, the throttle, the mixture, the propeller pitch) had come to mean going faster, or in any case that *something* was going to go faster (for example propeller revolutions). But not the wing sweep control. That one worked opposite. So as a pilot you wanted to slow down for a landing, and what would happen? That's right, you pull back the wing sweep, just like you pull back everything else. That's not good when you're close to the ground. Design-wise, what the wings *did* in a physical sense was completely uninteresting for you as a pilot. What their movement *meant* was what mattered. And so, the wing sweep control was changed. Engineers undaunted, pilots happy.

The message of such early human factors work is important. The most basic lesson is that design influences human performance. In fact, both good and bad design influence human performance. Bad design invites bad performance; it invites predictable kinds of human error. Good design, on the other hand, can enhance performance and prevent error. Human factors back then could be thought of as a separate layer of human limitations. Pilots, like other humans, could get tired, distracted, overloaded, used to some system rather than another, so they were not always equally watchful. Human factors people could deal with these limitations by tinkering with the engineered end of the human-machine interface. They needed to re-arrange the hardware at the place where human and system came together. Tweak this, re-shape that, re-adjust this, re-position that—make things error-tolerant and error-resistant. The human performance results were often startling: errors could be reduced dramatically. Engineers happy, pilots happy. So far so good.

Then airplanes started to become bigger and faster and heavier and more powerful and jet-engined and airlines wanted to fly in even lousier weather—and so things began to change. A bit, that is. On take-off, some early jet transports cartwheeled off the runway in the dark, apparently because of problems with judging pitch angles. Dark hole approaches, bad visibility approaches—they too presented their own set of problems related to keeping the aircraft on a glide slope. But again, technical fixes were right around the corner. PAPI's, flight directors, instrument landing systems—all of these could deal with the limitations of the human perceptual apparatus (as was the popular way to think about human performance back then). Where the human could not see, the radio waves could. They would beam that glide slope right up into the cockpit, through a flight director, just for the pilot to follow. Where the human would misjudge angles, red and white lights or flight directors would tell him the naked truth. Human limitations could be compensated by putting artificial extensions in the world that could look or feel further or more accurately than the human could. Once again human factors could be thought of as a separate layer of human limitations; a layer that could be engineered away by inserting more technology. Now technology was actually made to *do* something active for the human, rather than only sitting there preventing errors. Engineers happy, pilots happy. Things still going well.

Then came the computer. Now this was technology that really could do something for the human. Or so the idea went. A wave of crashes with computerized aircraft during the nineties proved just how much. Dialing a flight path angle of 3.3 while the airplane was actually in vertical speed mode near Strasbourg in 1992. Forcing an aircraft back on glideslope after inadvertently engaging the TOGA mode in Nagoya in 1994. Programming one waypoint instead of another near Cali in 1995. And many many more. "Computer mismanagement!", cried the engineers. "Too much automation!", cried some human factors people. "This is abusing automation!", cried one manufacturer, "These pilots mismanage perfectly trouble-free aircraft!", chimed in his colleague. "Get me my flight engineer back, or better still, a software specialist!", lamented some pilots. Engineers deeply disturbed, pilots unhappy, and human factors people thoroughly confused. This is where we are today.

Meanwhile, engineers work hard to fill the vacuum. "Just a teeny tiny bit more technology", they ask, "please let us add just a little bit more technology...and then we'll be allright. Then these problems won't occur anymore. We'll give you Enhanced GPWS instead of GPWS, how's that. We'll give you TCAS too, while we're at it. And what about a 3D vertical FMS flight path profile to prevent mismanagement of vertical modes? We can do it, really, we can show you how." More technology can thicken the layer of defense. It can put more buffer, more time, between the airplane and the mountainside. But new technology also introduces new error opportunities. When is that little colorful picture on your map display radar return and when is it EGPWS generated? Think you'll never get them mixed up? Think again. The idea that just a teeny tiny bit more technology is enough is misguided, because there will never be an end to it. New technology, new errors. New errors, more technology to resolve them. And so on. The challenge for human factors is instead to work with pilots to meaningfully anticipate the kinds of errors people are likely to make, and to then point the development of new technology in fruitful directions. This is what Frank Hawkins did for a long time.

But what else is human factors doing? It is scrambling to try to make sense of the events of the past decades by turning to its most reliable tool yet: invent new terms and concepts. “These are problems with situation awareness”, proclaim some wisely. Or, sexier still, “these are issues of shared mental models”, say those who claim that CRM has something to do with it too. "The problem is complacency", declares yet another. The result is a cheerful collection of labels that make their rounds in the aviation industry. Even accident investigators use these labels. “This crash is due to deficient CRM!” And pilots and manufacturers swap them as if they’re valuable hard cash. “Enhanced situation awareness if you buy our avionics!” chant vendors of cockpit technology, assuming everyone has at least a first clue of what precisely will be improved when they buy this stuff. We seem to be re-using, re-inventing or re-labeling the same vague phenomena, with nobody able to specify them in any greater detail. The problem is that the more these labels try to say, the less they really say. They result in Babylonian conditions, where everyone’s idea of for example “situation awareness” is as good or as valid or as meaningless as the next one.

Complacency as pseudo-science

Take complacency. Most textbooks on aviation human factors talk about complacency, even endow it with causal power, but very few define it. "Boredom and complacency are often mentioned" says one, in connection with the out-of-the-loop problem in automated cockpits. But which causes which is left unanswered (complacency causes out-of-the-loop, or out-of-the-loop causes complacency?). Complacency is not defined. Similarly, another states that "because autopilots have proved extremely reliable, pilots tend to become complacent and fail to monitor them". Complacency, in other words, can lead to monitoring failures, but complacency is not defined. Another explains that "as pilots perform duties as system monitors they will be lulled into complacency, lose situational awareness, and not be prepared to react in a timely manner when the system fails". Thus, complacency can cause a "loss of situational awareness", but complacency is not defined. Other researchers observed in one study that "complacency set in and arousal went down...to the detriment of attention and vigilance". Complacency was claimed to produce attention and vigilance decrements, but complacency was not defined. On the same page in a human performance and limitations in aviation textbook, the authors say that complacency is both a "*trait* that can lead to a reduced awareness of danger", and a "*state* of confidence plus contentment". In other words, complacency is at the same time a long-lasting, enduring feature of somebody's personality (a trait) and a shorter-lived, transient phase in somebody's performance (a state)—a combination which would literally be a psychological first.

It does not take long to conclude that complacency shares the following characteristics with pseude-science like Freud's psychoanalysis:

- substitution instead of decomposition
- immunization against falsification
- overgeneralization and over-application

Substitution instead of decomposition

Where complacency is "defined", the definition does not take the form of decomposition. This is fundamental to science: a reduction to more primitive concepts with clearer connections to the behavioral situation about which the concept ("complacency" in this case) pretends to speak. Definitions of complacency do not deconstruct, they simply substitute one label for another. Thus, complacency is equated with boredom; overconfidence; contentment; unwarranted faith; overreliance; and a low index of suspicion.

Immunization against falsification

The side-effect of substitution is scientifically even more damaging. Folk models do not give an articulated psychological mechanism that is responsible for the behavior observed. How is it that complacency produces vigilance decrements? How is it that complacency leads to a loss of situational awareness, a reduced awareness of danger, a detriment to attention? Might the mechanism responsible be the decay of neurological connections? Are processes of learning and motivation responsible? Or is it a matter of conscious trade-offs between competing goals in a changing environment? None of the descriptions of complacency available today offer any such deeper insight. This leaves claims that complacency was at the heart of a sequence of events immune against critique, against falsification. For example, a training captain in a recent issue of the Journal of Aviation Training asserts that severely compromised cockpit discipline results when any of the following attitudes are prevalent—arrogance, complacency and overconfidence. Nobody can disagree because the claim is underspecified. This is similar to psychoanalysts claiming that obsessive-compulsive disorders are the result of overly harsh toilet training which fixated the individual in the anal stage where now the id needs to battle it out with defense mechanisms. Similarly, when one pilot asking the other "Where are we headed" is interpreted as a "loss of situation awareness", this claim is immunized against falsification. The journey from context-specific behavior (people asking questions) to the explanatory psychological concept (loss of SA) is made in one big leap, leaving no trace for others to follow or critique. Current theories of situation awareness lack an articulated psychological model that explains why asking questions about direction represents a loss of situation awareness.

Overgeneralization

The lack of specificity and the inability to falsify folk models contributes to their overgeneralization. The most famous example of overgeneralization in aviation psychology must be the inverted U-curve, also known as the Yerkes-Dodson law. Ubiquitous in aviation textbooks, the inverted U-curve couples arousal with performance (without ever stating any units of either arousal or performance), where a person's best performance is claimed to occur between too much arousal (or stress) and too little, tracing a sort of hyperbole.

The original experiments (done by Yerkes & Dodson in 1908), however, were neither about performance, nor about arousal. They were not even about humans. Examining "the relation between stimulus strength and habit formation" the researchers subjected laboratory mice to electrical shocks to see how quickly they decided to go one pathway versus another. The conclusion was that mice learn best (that is, they form habits most rapidly) at anything other than during the highest or lowest shock. The results approximated an inverted U only with the most generous of curve-fittings, the X-axis was never defined in psychological terms but in terms of shock strength, and even this was dubious: Yerkes & Dodson used five different levels of shock which were too poorly calibrated to know how different they really were. The subsequent overgeneralization of the Yerkes-Dodson results (to no fault of their own, incidentally) has confounded stress and arousal, and after a century there is still no evidence that any kind of inverted U relationship holds for stress (or arousal) and human performance. Overgeneralization takes narrow laboratory findings and applies them uncritically to any broad situation where behavioral particulars bear some *prima-facie* resemblance to the phenomenon that was produced under controlled circumstances.

Other examples of overgeneralization and over-application include "perceptual tunneling" (putatively championed by the crew of an Eastern airlines L-1011 that descended into the Everglades after its autopilot was inadvertently decoupled) and the loss of effective crew resource management as major explanation of accidents. A most frequently quoted sequence of events with respect to CRM is the flight of an iced-up Air Florida Boeing 737 from Washington National Airport in the winter of 1982 that ended shortly after take-off on the 14th street bridge and in the Potomac river. The basic cause of the accident is said to be the co-pilot's unassertive remarks about an irregular engine instrument reading (in fact, the co-pilot was known for his assertiveness), something that hides many other factors with equal or more explanatory power, including air traffic control pressures, the controversy surrounding rejected take-offs close to decision speed, the sensitivity of the aircraft type to icing and its pitch-up tendency with even little ice on the slats, and amgibuous engineering language in the airplane manual to describe the conditions for use of engine anti-ice.

The old view of human error

The way complacency, or lack of flight discipline, is used as explanation for human performance difficulties fits the tradition of the old view of human error. This view holds that:

- Human error can cause accidents;
- Complex systems are basically safe, were it not for the erratic behavior of unreliable people in it;
- Human errors come as an unpleasant surprises. They are unexpected and do not belong in the system, nor do they originate there. Errors are introduced to the system only through the inherent unreliability of people.

Epitomizing the old view of human error, in a form that could be called "The Bad Apple Theory" Tony Kern characterizes "rogue pilots" as extremely unreliable elements, which the system, itself basically safe, needs to identify and contain or exile:

"Rogue pilots are a silent menace, undermining aviation and threatening lives and property every day. Rogues are a unique brand of undisciplined pilots who place their own egos above all else—endangering themselves, other pilots and their passengers, and everyone over whom they fly. They are found in the cockpits of major airliners, military jets, and in general aviation...just one poor decision or temptation away from fiery disaster."

The system, in other words, contains bad apples. In order to achieve safety, it needs to get rid of them. Individual differences among pilots are of course undeniable, but to build an explanation of system safety solely on its grounds is oversimplified and risks dealing only with the symptoms of human error—not the causes.

In a current issue of FLIGHT International (6-12 June 2000) I am reading that charges will be brought against the pilots who flew a Greek Falcon 900 VIP jet which had a malfunctioning pitch feel system. A preliminary investigation indicates that severe oscillations during descent killed seven of their unstrapped passengers in the back. Significant in the sequence of events was that the pilots "ignored" the relevant alert light in the cockpit as a false alarm, and that they had not switched on the fasten seatbelt sign from the top of descent, as recommended by Falcon's procedures. Dramatically, these pilot oversights were captured on video, shot by one of the passengers who died not much later. The pilots got away alive from the upset, as they were wearing their seatbelts.

The fact that pilots would "ignore" the relevant warning indication is surprising. So surprising, in fact, that it is hard to believe. You would think that the pilots were too busy getting their aircraft back under control to connect the light with what was going on (bugger the little light—it would probably not have been the only one). Or they had no idea what the light had really been about in the first place. The label "ignored" implies willfull disregard. It implies that the pilots should have taken the warning to heart, but chose not to; they could not be bothered. Their error was crucial in allowing the accident to happen. Which is why they should stand trial. In this old view of human error, we should:

- Find evidence for erratic, wrong or inappropriate behavior;
- Bring to light people's bad decisions; their inaccurate assessments; their departures from written guidance;
- Single out particularly ill-performing practitioners, to show how some people behave unrepresentatively—not the way the system would like to see.

Accordingly, progress on safety is driven by one unifying idea: Protect the system from unreliable people. This protection against the vagaries of human behavior can be achieved by:

- Tightening procedures and close regulatory gaps. This reduces the bandwidth in which people can operate, leaving less room for erroneous performance;
- Introducing more technology to monitor or replace human work. If machines do the work, then humans can no longer make errors doing it. And if machines monitor human work, they can snuff out any erratic human behavior;
- Making sure that defective practitioners do not contribute to system breakdown again. Put them on "administrative leave"; demote them to a lower status; educate them to behave better next time; instill some fear in them and their peers by dragging them into court.

In this view of human error, investigations can safely conclude with the label "human error"—by whatever name (for example: ignoring a warning light, violating a procedure, complancency, lack of discipline). Such a conclusion and its implications supposedly get to the causes of system failure. That, at least, is the idea.

The shortcomings of this first view of human error are severe and deep. Progress on safety based on these ideas is an illusion:

- Focusing on individual failures does not take away the underlying problem. Removing or prosecuting supposedly "defective" practitioners fails to remove the potential or groundwork for the errors they made. As it turns out, in the Falcon case, the aircraft had been flying around for a long time with a malfunctioning pitch feel system (As in: Oh that light? Yeah, that's been on for four months now). These pilots happened to inherit a systemic problem that really was largely the responsibility of others.
- Adding more procedures or threatening to enforce existing ones does not guarantee any compliance. Seatbelt sign on from top of descent in a VIP jet? The layout of furniture in these machines and the way in which their passengers are pressured to make good use of their time by meeting, planning, working, discussing, does everything to discourage people from strapping in any earlier than strictly necessary. Pilots can blink the light all they want, you could understand that over time it may become pointless to switch it on from Flight Level 410 on down. And who typically employs the pilot of a VIP jet? Exactly, the person in the back. So guess who can tell who what to do. And why having the light on only from TOD? This is hypocritical—only in the Falcon 900 upset was that relevant because loss of control occurred during descent. But other accidents with in-flight deaths occurred during cruise. Procedures are too strict to cater for this kind of natural variability.
- More technology does not remove the potential for human error, but relocates or changes it. A warning light does not solve a human error problem, it creates new ones. What is this light for? What do we do about it? What do we do to make it go away? It lit up yesterday and meant nothing. Why take it serious today?

So why would anyone adhere to the old view of human error? There are many reasons. One is that it is a relatively straightforward approach to dealing with safety. It is simple to understand and simple, and relatively cheap, to implement. In the aftermath of failure, enormous pressure can exist to save the public image of an aircraft or operator, even if it means that operators and regulators are running from pillar to post, putting out one little symptomatic fire after the other. To the public, this can look good; this can look like a serious countermeasure against safety threats. Taking out defective pilots is always a good start to saving public face. It tells people that the accident is not a systemic problem at all, but just a local glitch in an otherwise perfectly smooth operation.

Another reason to adhere to the old view of human error is that practitioners in safety-critical domains typically assume great personal responsibility for the outcomes of their actions. As one airline captain said: "If I didn't do it, it didn't happen." Practitioners get trained and paid to carry this responsibility. In fact, practitioners take pride in having this responsibility, and failing to live up to it is generally seen as a personal failure. In many domains where human error matters, investigators themselves are practitioners or have been practitioners, which infuses investigative practice with the culture of those who get investigated. This, of course, has advantages. But it makes it easy for investigators to overestimate the freedom of choice allotted to his or her fellow practitioners. I am reminded of an incident where a crew member accepted a different runway with a more direct approach to the airport. The crew got in a hurry and made a messy landing that resulted in some minor damage to the aircraft. Asked why they accepted the runway, the crew member cited a late arrival time and many connecting passengers on board of his aircraft as reasons. The investigator's reply was that real pilots are immune to those kinds of pressures.

But the reality is that people, pilots in this case, simply do not operate in a vacuum, where they can decide and act all-powerfully. Instead, their work is subject to and constrained by all kinds of factors outside of their control—factors that will help push their trade-offs and decisions one way or another. The reality is that individual responsibility is not always matched by individual authority, because that authority is restricted by other people in the system; other parts of the system; other pressures in the system. In the Falcon's case, it was found that there was no checklist that told pilots what to do in case of a pitch feel indication. The procedure to avoid the oscillations would have been to reduce airspeed to less than 260 knots indicated. But it wasn't in the book. It wasn't in the cockpit. How, really, can anyone say that pilots "ignored" a light for which there was no procedure available? You cannot expect that a pilot would or should have come up with the arbitrary airspeed of 260 knots indicated by just thinking through the light a little bit and what it perhaps could have meant. Factors from the outside seriously constrained what the pilots could do or could have done. Problems already existed with this particular aircraft. There was no procedure to deal with the light. To think that human errors are just a matter of personal choice and causes of accidents, is to think primitively. It is to ignore (yes, "ignore") the real path to progress on flight safety.

Nature or nurture?

Progress on safety with the old view of human error is problematic. Exhorting people to be less complacent (or more disciplined—see Kern, 1998) "is unlikely to have any long-term effect unless the exhortation is accompanied by other measures... A more profound enquiry into the nature of the forces which drive the activities of people is necessary in order to learn whether they can be manipulated and if so, how." (Hawkins, 1987, p. 127).

Aerospace safety seems to face a latter-day version of the persistent nature-nurture debate in psychology. Are bad pilots born? Or are they bred? Is complacency an inherent trait, or is it nurtured through interaction with the environment in which people work? Fitts and Jones 47' must have had their minds made up half a century ago. Their evidence was undeniable: they found that the behavior that was called human error, was actually systematically connected to features of people's tools, tasks and operational environment. There was nothing mysterious or elusive about human error. If researchers could understand and modify the situation in which humans were required to perform, they could understand and modify the performance that went on inside of it. Central to this idea is the local rationality principle (Woods *et al.*, 1994). People do reasonable, or locally rational things given their tools, their multiple goals and pressures, and their limited resources. Their assessments and actions make sense given the situation that surrounds them at the time. Human error is a symptom—a symptom of irreconcilable constraints and pressures deeper inside a system; a pointer to systemic trouble further upstream. Human error is uninteresting in itself. It is not a separable category of unexpected sub-standard behavior—it is a label, applied in hindsight to fragments of empirically neutral, locally rational assessments and actions. This is the basis for the new view of human error.

The new view of human error

The new view of human error holds that:

- Systems are not basically safe;
- People are central to creating safety;
- Their "errors" are indications of irreconcilable goals and pressures farther up-stream.

The complex, dynamic systems in which people carry out their work are themselves inherent contradictions between safety and many other goals that are simultaneously active (on-time performance, fuel use, customer comfort, etc.). Most systems do not exist just to be safe; they exist to provide a product or a service. Such basic organizational dialectic between protection and production is not insulated or resolved in higher echelons. It is pushed down into individual operating units, to be sorted out by operational personnel in the form of thousands of daily decisions and trade-offs. Organizations typically send many messages about the importance of these other goals in subtle or less subtle ways ("We are the No 1 on-time airline!"), pushing local trade-offs in certain directions.
It is easily claimed (even by pilots themselves) that good practitioners are immune to these kinds of pressures, but the companies that employ them would not want them to be. Practitioners' expertise is in part the ability to pursue and reconcile the multiple goals and pressures that are simultaneously active, including safety.

Borrowing from safety

One indication that goals and pressures other than safety are at work, are departures from the routine—cases in which practitioners (unknowlingly) borrow from safety in order to achieve other system goals. Such departures may be a late runway change that helps a scheduled arrival; the skipping over a checklist to make a slot time, and so forth. When looked at in isolation, these departures from the routine can be interpreted as evidence of deviance: of complacency or poor discipline or even recklessness. But in isolation these events are hardly interesting. What really gives them meaning is their context, which often shows that departures from the routine have, over time, become routine themselves. Pilots say of late runway changes: we do it all the time. Or slot pressures (or fuel savings) have pervaded many decisions and trade-offs that are made on flightdecks company-wide. Departures from the routine can become so routine, in fact, that they become the new norm against which actual behavior is contrasted. This means that it is compliance, not deviance, that accounts for the behavior observed. Pilots who are unwilling to take a direct towards a new runway, for example, don't play ball, they hold up the flow, they waste time and fuel. The pilot corps of one airline even refers to "Operating Manual Worshippers".

Although some kind of departure from the routine often forms an ingredient in an accident sequence, the opposite is not true: departures from the routine rarely lead to accidents. In fact, the gradual redefinition of what is normative behavior and what is acceptable risk occurs because departures from the routine do not lead to trouble but offer immediate, concrete and measurable rewards: lower fuel bills; on-time arrivals; happy customers. How much is borrowed from safety in order to achieve this, however, is impossible to measure. In fact, the lack of adverse outcomes each time is the only "measurable" index of safety, confirming it was safe to depart from the routine (once again). As Karl Weick describes:

"Reliability is invisible in the sense that reliable outcomes are constant, which means there is nothing to pay attention to. Operators see nothing, and seeing nothing, presume that nothing is happening. If nothing is happening and they continue to act the way they have been, nothing will continue to happen. This diagnosis is deceptive and misleading because dynamic inputs create stable outcomes."

But people do not just continue what they have been doing, encouraged by constant non-event outcomes. There is evidence that in the face of a continuous lack of adverse consequences, people and organizations gradually tweak up the returns from their departures from the routine, thereby unknowingly borrowing more and more from safety as time passes. As Diane Vaughan showed from the inside of the organization that launched the Space Shuttle Challenger in 1986, complacency is based on a *justified* assumption of satisfactory system state, since there is no evidence to the contrary. But there is more: the assumption of satisfactory system state is *institutionalized*—encapsulated in its own culture through the repeated and eventually entrenched use of language and rituals. She called this process the "normalization of deviance", and observed that:

”Even when technical experts have time to notice and discuss signals of potential danger in a well-attended meeting prior to putting the technology into action, their interpretation of the signals is...shaped by a still wider system that includes history, competition, scarcity, bureaucratic procedures, power, rules and norms, hierarchy, culture and patterns of information.”

Complacency, in other words, is not the individual feature of defective or immorally calculating people. It is a feature of entire organizations, nurtured through their interaction with an environment where risk (i.e. how much is being borrowed from safety) is hard to measure and where the absence of adverse consequences doubles as justification and encouragement to finetune the pursuit more concrete system goals.

Progress on aerospace safety in the new view of human error

The new view of human error opens opportunities for progress on aerospace safety since it points to more promising areas where we can invest in countermeasures (more promising than exiling defective practitioners, overproceduralization or technical fixes that create new performance problems). It also shows where the rubbing points and obstacles are. For one, it is a waste of time to supplant the traditional "human error" (under whatever fashionable guise) with "designer error" or "organizational error". People higher up in an accident chain act locally rational too—their trade-offs and focus of attention make sense given their situation. Each blunt end is also a sharp end—where pressures can be high, stakes serious, goals multifarious and resources limited. Whether operator, designer or manager, there are no limits to human fallibility in a pressurized, resource-constrained world.

Investing in human resilience

Given the universality of fallibility, the surprise is not that accidents happen. The surprise is that accidents do not happen more often. Systems are not basically safe: accidents are to be expected since their ingredients are baked into the very nature of how systems are designed and operated. Failure, not success, is inherent. The fact that success does not come automatically, but is rather the result of human effort, has led a number of researchers to abandon the quest for the sources of human error altogether. They now seek the origins of human expertise and resilience instead—examining people's ability to routinely manage immensely constrained and ambiguous situations.

I wonder and I will keep on wondering whether human factors has done itself a favor by sponsoring the invention of the sort of pseudo-psychological labels we find everywhere today. But one thing is clear. Human factors is no longer limited to tinkering with the hardware end of the human-machine interface. It is no longer a separate layer of human limitations that we can engineer away. No, human factors has made inroads into the very heart of operational practice. It is trying to conquer what goes on in the minds of the people at the controls. It claims it can now speak meaningfully about things such as decision making, situation assessment, crew interaction and a lot more. If I remember well, these things used to fall under what we once called “airmanship”. But now it’s human factors. So there you have it. With human factors topping the list of contributors to incidents and accidents, it never harms to gain a better understanding of what it is all about. This goes both for human factors people themselves and for those in practice who have to rely on the knowledge produced by them.

The author is Assistant Professor in the Centre for Human Factors in Aviation at the Linkoping Institute of Technology in Sweden and is a glider flight instructor and tow pilot and also flies parachutists. He has completed first officer training on the DC-9.
His books include "The Field Guide to Human Error", which will be published by Cranfield University Press in early 2001, and "Coping with computers in the cockpit" which is published by Ashgate, UK (1999).

Bibliography

Aeronautica Civil de Colombia (1996). *Aircraft accident report: Controlled flight into terrain, American Airlines flight 965, Boeing 757-223, N651AA near Cali, Colombia, December 20, 1995.* Bogota, Colombia: Aeronautica Civil.

Billings, C.E. (1996). Situation Awareness Measurement and Analysis: A Commentary. In D. J. Garland, M. R. Endsley (Eds.), *Experimental Analysis and Measurement of Situation Awareness*, pp. 1-5. Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

Billings, C. E. (1996). *Aviation automation: The search for a human-centered approach.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Buck, R. N. (1995). *The pilot's burden: Flight safety and the roots of pilot error.* Ames, IA: Iowa State University Press.

Campbell, R. D., & Bagshaw, M. (1991). *Human performance and limitations in aviation.* Oxford, UK: Blackwell Science.

Cook, R. I., Render, M., & Woods, D. D. (2000). Gaps in the continuity of care and progress on patient safety. *BMJ, 320*, 791-794.

Dekker, S. W. A. (in press). *The field guide to human error.* Bedford, UK: Cranfield University Press.

Fitts, P. M., & Jones, R. E. (1947). Analysis of factors contributing to 460 'pilot error' experiences in operating aircraft controls. *Memorandum Report TSEAA-694-12*, Aero Medical Laboratory, Air Material Command, Wright-Patterson Air Force Base, Dayton, Ohio, July 1, 1947.

FLIGHT International (2000), 6-12 June, anonymous.

Goteman, O. (1999). Automation policy or philosophy? Management of automation in the operational reality. In S. W. A. Dekker & E. Hollnagel (Eds.), *Coping with computers in the cockpit,* pp. 215-222. Aldershot, UK: Ashgate Publishing Co.

Hart, S. G. (1988). Helicopter human factors. In E. L. Wiener & D. C. Nagel (Eds.), *Human factors in aviation*, pp. 591-638. San Diego, CA: Academic Press.

Hawkins, F. H. (1987). *Human factors in flight.* Aldershot, UK: Gower technical press.

Hollnagel, E. (1997). Measurements and models, models and measurements: You can't have one without the other.

Kern, T. (1998). *Flight Discipline.* New York, NY: McGraw-Hill.

Kern, T. (1999). *Darker shades of blue: The rogue pilot.* New York, NY: McGraw-Hill.

Langewiesche, W. (1998). *Inside the sky.* New York, NY: Pantheon.

Meister, D. (in press). Human factors/ergonomics at the brink of the 21st century. *IEA Journal of Ergonomics Design.*

Ministère de l'equipment, des transports et du tourisme (1993). *Rapport de la commission d'enquete sur l'accident survenu le 20 Janvier 1992 près du Mont Saint Odile (Bas Rhin) a l'Airbus 320 immatriculé F-GGED exploité par la compagnie Air Inter.* Paris, France: METT.

North, D. M. (2000). Let judicial system run its course in crash cases. *Aviation Week and Space Technology, May 15*, p. 66.

O'Hare, D., & Roscoe, S. (1990). *Flightdeck performance: The human factor.* Ames, IA: Iowa State University Press.

Parasuraman, R., Molly, R., & Singh, I. (1993). Performance consequences of automation-induced complacency. *The International Journal of Aviation Psychology, 3*(1), 1-23.

Perrow, C. (1984). *Normal accidents: Living with high-risk technologies.* New York, NY: Basic books.

Reason, J. T. (1997). *Managing the risks of organizational accidents.* Aldershot, UK: Ashgate Publishing Co.

Sarter, N. B., & Woods, D. D. (1987). Teamplay with a powerful and independent agent: Operational experiences and automation surprises on the Airbus A-320. *Human Factors, 39*(4), 553-569.

Starbuck, W. H., & Milliken, F. J. (1988). Challenger: Fine-tuning the odds until something breaks. *Journal of Management Studies, 25*(4), 319-340.

Stokes, A., & Kite, K. (1994). *Flight stress: Stress, fatigue and performance in aviation.* Aldershot, UK: Avebury Aviation.

Vaughan, D. (1996). The Challenger lauch decision: Risky technology, culture and deviance at NASA. Chicago, IL: University of Chicago Press.

Weick, K. E. (1990). Organizational culture as a source of high reliability. *California Management Review, 29*, 112-127.

Wiener, E. L. (1988). Cockpit automation. In E. L. Wiener & D. C. Nagel (Eds.), *Human factors in aviation*, pp. 433-462. San Diego, CA: Academic Press.

Wiener, E. L. (1989). *Human factors of advanced technology ("glass cockpit") transport aircraft* (NASA contractor report No. 177528). Moffett Field, CA: NASA Ames Research Center.

Woods, D. D., Johannesen, L. J., Cook, R. I., & Sarter, N. B. (1994). *Behind human error: Cognitive systems, computers and hindsight.* Dayton, OH: CSERIAC.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of comparative and neurological psychology, 18*, 459-482.