ELIMINATING
"COCKPIT-CAUSED"
ACCIDENTS.

Error-tolerant Crew Procedures
for the 21st Century.

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Contents

Executive Summary. ______ *3*

Bringing Standard Operating Procedures into the 21st Century. ______ *4*

The challenge: achieving a large reduction in the accident rate. ______ **4**

Can training fix the problem? ______ **4**

The role of Standard Operating Procedures (SOPs) ______ **6**

From "pilot", to "pilots", to "crew". ______ **7**

The role of Crew Resource Management. ______ **8**

Ranks, roles, and functions - making clear what we mean. ______ **10**

How reliable is our control system? ______ **11**

The cultural conflict. ______ **13**

How well are we doing? ______ **15**

Considerations in SOP design. ______ **15**

A Crew Co-ordination SOP for the 21st century. ______ **17**

Benefits in different cultures. ______ **18**

Where's the data? ______ **19**

Where do we go from here? ______ **21**

An implementation strategy to reduce the "Cockpit-caused" accident rate. ______ **22**

Appendix 1: Common objections to the concept. ______ *25*

Appendix 2 - objections to the data. ______ *27*

Appendix 3: An airline case history - four CFIT "close calls". ______ *29*

Appendix 4: "First Officers' Sectors." ______ *32*

Appendix 6: a specimen SOP allocation of duties. ______ *44*

About the author. ______ *46*

Executive Summary.

Airline accidents occur too frequently. Human errors, particularly by flight crews, remain the most important single contributor to the current accident rate. Achieving the desired target requires a global reduction in collective crew errors of the order of 80%, but two decades and more of attempts to achieve this by improving the performance of individual crew members shows little prospect of meeting that objective.

A primary safety tool for flight crews is their Standard Operating Procedures (SOPs). However, an analysis of conventional SOPs for crew co-ordination from and "engineering" perspective shows that they are unlikely to achieve the necessary reliability, as subordinate crew members cannot be relied on to make a switch from "helping" to "opposing" the pilot flying when necessary. A "humanistic" analysis also indicates that this kind of failure is inherent in the culture of most societies.

Statistics on airline accidents, as well as much anecdotal and other evidence, indicate that the breakdown of crew procedures which require co-pilots to make this "mode switch" from "assist" to "prevent" is in fact a major factor in "crew-caused" accidents. An alternative, "delegated flying" method of operation should in theory be more reliable from both perspectives. Comparative data indicates that this alternative procedure does indeed produce significantly better results, and could possibly reach the 80% error reduction improvement needed.

The alternative "delegated flying" SOP incorporates techniques specifically recommended in many accident studies, as well as one of the fundamental problem-solving tools recommended in most CRM training. Consequently, there is an unarguable case for the industry to make changes to incorporate the concept of delegation of routine non-critical flying tasks into normal operating procedures for all transports with a minimum crew of two pilots. An implementation strategy is recommended which should enable the industry to achieve its safety target on all multi-crew transport aircraft at virtually zero cost, and with no requirement for additional equipment.

The paper is self-contained, but the Notes and Appendices contain additional explanatory material, references, examples, and comment on the questions which a radical change such as is proposed normally generate.

Note: original versions 1997-99. Text reviewed periodically since then.

2013 review: since the time of writing, other improvements in aircraft design, equipment and operation have prevented a major increase in total accident numbers. Nevertheless, the causal factors described here continue to result in unacceptable loss of life, injuries and damage, rendering the paper's basic message as valid today as at its time of writing.

Bringing Standard Operating Procedures into the 21st Century.

The challenge: achieving a large reduction in the accident rate.

The air transport industry faces a major challenge. There is a wide consensus that unless we dramatically improve our overall safety performance, there will be an unacceptable increase in the total number of accidents over the coming years[i]. Flight safety is critically dependent on flight crews solving problems correctly, and the majority of accidents now involve failure by the crew to resolve some sort of problem affecting them, their aircraft and/or their environment. In almost all cases a solution was available, but for various reasons was not applied. This situation has been recognised for at least thirty years, and various remedies have been proposed, but so far they are having only marginal effects on the total safety picture, basically because they tend to address individual symptoms of the problem. They are not sufficiently radical to provide the step-change improvement actually needed across all segments of the business, from old to new aircraft technology, and from regional and commuter carriers to major intercontinental airlines.

The fact is that some of the basic problem-solving tools provided to crews are simply no longer adequate for the demands being made on them. To eliminate these accidents it is essential to focus on detecting and correcting errors, rather than on unrealistic attempts further to reduce them. We must make flight operations "error-tolerant". Flight crews, and specifically airline flight operations managements, need to apply both basic engineering safety principles, and elementary human relations concepts, to the operational problems that crews encounter.

Can training fix the problem?

We know that both global, generalised accident data,[ii] and detailed studies such as the NTSB's 1994 study of U.S. airline accidents[iii], indicate that failures apparently originating in the flight deck are the predominant primary cause in airline accidents. Typically, the approach to dealing with this is by crew training and education, intended to improve crew performance by improving the quality of individual crew members.

But accidents are not generally due to single failures of sub-standard individuals: usually, it is the way that previously "satisfactory" individuals received and processed information in a specific instance which was at fault. That is why the enormous amount of effort expended in training has not produced the desired result. The origins of accidents in complex systems such as aviation, where the probability of accidents is low but the consequences are very severe, lie in the organisation and system management: the individuals involved in the actual accident are merely the final links in the chain of weaknesses[iv].

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[i] Numerous studies by manufacturers, ICAO, Flight Safety Foundation, White House Commission on Aviation Safety and Security, etc.

[ii] ibid.

[iii] NTSB Safety Study: A review of Flight Crew-involved Major Accidents of US air carriers, 1978 through 1990. (NTSB/SS 94/01)

[iv] See articles and work by James Reason, Professor of Psychology, University of Manchester, e.g. Bureau of Air Safety Investigation Journal, September 1991; Proceedings of IATA Human Factors Seminar, Bahrain, March 1995, etc..

To reduce the accident rate sufficiently by training individual crew members, it would be necessary to improve crew member "quality" by about an order of magnitude. But most crews already operate in what they believe to be a very safe manner - most airline pilots would rate their work as being considerably safer than many other aspects of their lives. It is certainly safer than most other types of aviation. Whilst airline pilots generally accept that there is a need for improvement, they see the problem as inadequate or inappropriate tools to do the job - not a lack of good qualities within the pilots themselves.

It is extremely improbable that we will be able to convince every individual pilot that he or she needs personally to be ten times safer in future than they are today - let alone actually to make them so. Comparing accident and incident statistics with typical transport pilot career flying exposure will quickly show that most pilots rarely experience significant incidents[v], and those that they do experience are not generally crew-originated. Indeed, most incidents involve the crew members preventing errors originating elsewhere from becoming accidents. Airline management pilots also generally have far less exposure than line pilots, and are even less likely to experience a problem in person, so their perception of individual risk is probably further skewed by this[vi]. It is hard to convince individual pilots that although they personally may never have experienced even a hint of a specific problem, the risk from that cause may still be unacceptably high, in fact so high that it may be necessary to alter their working methods to deal with that risk.

Around the world, there are also economic and political factors tending to drive the quality of crew "raw materials" down, not up[vii]. It follows that since we still need to reduce

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[v] A pilot flying a 35 year career with a high efficiency shorthaul airline operating 1000 hours per annum on 1 hour sectors would fly 35,000 flights in his entire career. One with a short (say 15 year) career with an inefficient, ultra-long haul airline flying 700 hours a year on 14 hour average sectors would fly 750 flights in his entire career. Within these extremes, a typical pilot might be taken as having a 10,000 to 15,000 flight career exposure.

The global accident rate is approximately 1 accident per million flights. It is generally accepted that for every accident there are a number of serious incidents and a larger number of less serious events. If each accident is associated with 20 serious incidents, and each serious incident with 50 minor ones, there would be 1000 minor events per accident, or one per 1000 flights. The typical pilot in a two-crew environment might therefore see 20 or so such events in his career, and at realistic actual exposure rates, this could vary between say one or two a year to one a decade.

These of course are relatively minor events from all causes, the vast majority of which would not only NOT be crew caused, but in fact events due to other causes which the crew had successfully prevented from becoming more serious events. To validate these broad numbers, one major airline with a highly sophisticated air safety incident reporting and analysis system receives approximately one to two event reports (for all causes), per pilot, per year. Approximately one in twenty of these is classified as being of significant risk.

[vi] Managers may be selected because of above-average initial flying skills. Managers may fly as little as one or two flights per month. Because of their position they are highly motivated to demonstrate adherence to SOPs, and the pilots they fly with are similarly motivated. Hence managers' views of actual line operations may be skewed. There is also significant anecdotal evidence that technical errors by managers may be given less critical treatment by their peer managers because of political and organisational factors.

[vii] In many countries with advanced existing aviation industries, the demographic picture of age and impending retirements is causing average experience levels to fall. In such countries expanding operations also can cause a rapid turnover of pilots between smaller and/or regional airlines and larger international carriers. As an example of how even the popular press is becoming aware of this, on April 28 1997 the cover story in "USA Today" headlined *"Hiring boom dries up pool of skilled flyers",* and contained the following quotations. "As the supply of qualified pilots shrinks, airlines will be forced to lower their standards or decrease hiring. And they're less likely to cut hiring" says Robert Besco, president of aviation training consultants Professional Performance Improvement. "*I see a near-crisis in less than a decade in terms of pilot quality*". The demand for pilots may

the "cockpit caused" accident rate by a factor of 5 to 10, we cannot rely on improved training of individual pilots as the **primary** means to improve the quality of either existing or future crews, in order to reduce cockpit-caused accidents. We need some radical thinking, and it is in the crew procedures area that the biggest, quickest and by far the lowest cost improvements can be made[viii]. However, this is also the area in which entrenched prejudices (driven largely by our misleading subjective experience of risk) pose the biggest obstacles to achieving our improved flight safety objectives. In other words: we pilots may be our own worst enemies, and some traditional concepts in flight operations are now actively hindering our safety record[ix].

The role of Standard Operating Procedures (SOPs)

"Non-adherence to SOPs" is a primary accident cause. Some recent studies give clues as to why this can happen[x], but they fail to address a basic question: is the whole philosophy underlying most airline crew co-ordination SOPs still in fact valid?

The vast majority of aircraft, including all basic training types, are designed from the outset for a minimum crew of only one pilot. Licensing authorities base not only the initial qualification for a commercial licence, but also their recurrent qualification requirements for a multi-crew transport, on the basis of single pilot operation. While the need for each pilot individually to be capable of all operational functions is self-evident, the large transport

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also put pressure on the FAA to drop the rule that forces pilots to retire at age 60. "It's not a problem of quantity, but of the *quality* of pilots. And that pool (of qualified pilots) will be drying up", says Tim Cole of the Professional Pilots Federation, a 2,000 member group appealing the FAA's decision last fall to keep the rule. End quotes: emphasis supplied.

Expansion of airline operations in developing countries is leading to demand for educated trainees which may outstrip their basic educational system capabilities. In regions seeing extensive deregulation the consequent mushrooming of new entry carriers, leads to intensive pressures to lower costs, with consequent impact on pilot pay and conditions which make joining the profession less attractive to qualified and educated candidates. In some cases this also results in significant degradation of training as a cost-saving measure. Some airlines have instituted processes under which pilots are expected to pay for their own training, with obvious potential repercussions for minimizing training in order to avoid cost. The inquiry into the Birkenair B757 accident in 1996 found that although the crew's training met the minimum legal requirements, it was not effective and the crew were seriously under-trained in many respects.

[viii] Technology improvements such as Enhanced GPWS are costly and applicable mostly to newer aircraft. There are also integration problems with adding warning systems into existing flight decks. Increased crew training may be applicable to all types of operation but costs money, which those operators most likely to benefit from it are least likely to wish to spend. There is also some evidence that "add-on" training such as CRM may "wear off" after a few years and hence need reinforcement.

Changing crew duty allocations requires minimal effort and cost since it simply replaces existing procedures with better ones: the one-off cost of training is in itself small, and the change reinforces the benefits of add-on training such as CRM. Subsequent reinforcement may well be unnecessary since the new procedures by definition incorporate improved CRM techniques, and are routinely used in everyday operation and normal recurrent training.

[ix] An anonymous Australian pilot commented recently on a pilot Website: "I believe that those who refuse to consider (changing the conventional) system do so mainly out of a misplaced belief that it would be somehow 'un-macho' to do so - an admission that they can't handle it all single-handed, as they've always done to date. …….The reason the procedure hasn't changed to something like the (delegated) one much earlier, (and the reason it probably won't change), is that we are, as pilots, without any shadow of a doubt (and with the possible exception of those old men locked inside the cloisters of the Vatican) - the most conservative and resistant-to-change group in the world.

[x] see Degani and Wiener: NASA Contractor Report 177642 "On the Design of Flight Deck Procedures", June 1994.

aircraft with which we are concerned are fundamentally different in that they are **not** operated by a single pilot, but by a **crew** of at least two pilots. This mismatch - do we deal with a pilot or a multi-person crew? - lies at the root of many transport aircraft accidents, for the air transport industry still tends to think primarily of the **pilot** and of only as an afterthought[xi] of "the **crew**".

A crucial question addressing the problem of crew-caused accidents was asked at an SAE conference on Human Error Avoidance in 1990[xii]. It was this:

"When the operational profile is analysed to establish crew duties, independent checks by the pilot-not-flying, and checklist sequences, how rigorous are we in actual practice? How completely are the assumptions wrung out, documented, and cross-checked? What process is followed when a procedure change is proposed? Who performs the new "failure mode and effects analysis"? Who is in charge of the master "dual-channel integrity" document?"

It asks, in effect, who analyses crew procedures to ensure that the crew function safely as a system? And the answer is that usually, **no-one** does.

From "pilot", to "pilots", to "crew".

In single-pilot aircraft it is inevitable that the one pilot is responsible for all tasks. Single-pilot aircraft are used for private, military, and general aviation, where the accident rate is **higher** than in air transport. However, because the consequences of airline accidents are so enormous, in human and financial terms, reducing the **transport** accident rate (rather than that of the other types of flying) is vital. If we are to achieve this objective, we can no longer operate big transport aircraft as if they are just large, complicated and expensive versions of the Piper Cub. Instead it is essential to ensure that SOPs are written which wring every ounce of benefit from the fact that we normally[xiii] have at least a two-pilot crew available.

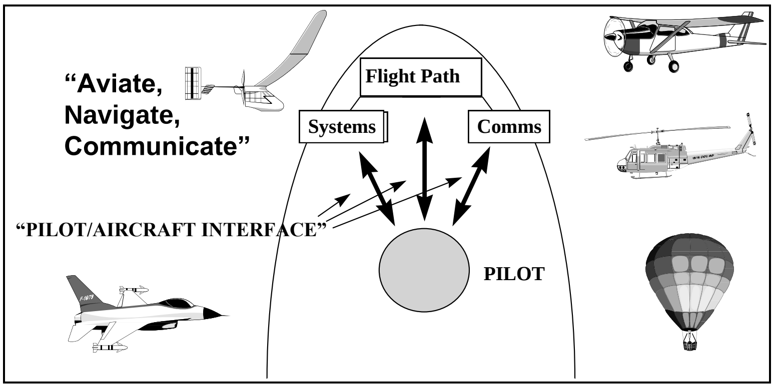

Figure 1: Single Pilot Operation

[xi] A "guesstimate" by the author is that in technical documents relating to human factors in the context of flight deck safety issues, "the pilot" is referred to ten times as often as "the crew", even when the latter term would actually be just as appropriate.

[xii] Keynote speech: "Control of Crew-Caused Accidents - the Sequel". Earl Weener, Chief Engineer, Airworthiness, Reliability and Maintainability, and Safety, Boeing Commercial Airplane Group.

[xiii] It is recognized that pilot incapacitation is a possibility - that is a fundamental reason why it is essential that every pilot demonstrate an ability to perform all tasks. However, very few accidents have ever occurred solely as a result of degradation from two to one pilot: in most, two "fully functional" pilots were available, but the full capability of both was not actually used.

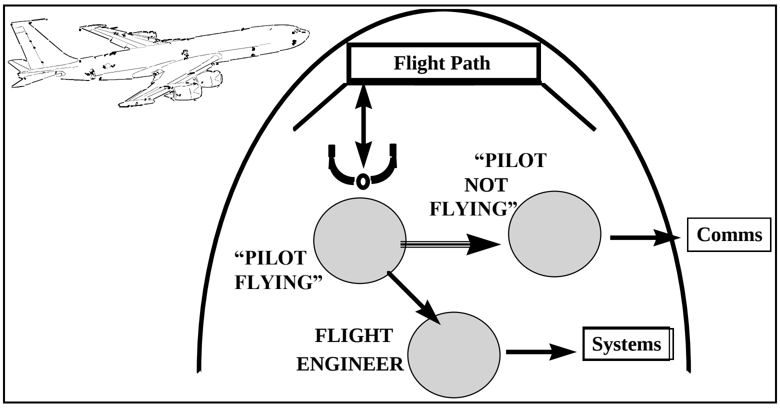

Figure 2: Conventional multi-crew operation

As the original single-pilot airmail aeroplane grew into the larger transport, the traditional operational concept recognised that the single pilot could no longer handle everything himself. So functions such as communication and systems operation were delegated to assistants. Co-pilot, flight engineer, navigator, radio operator were added, though all but the co-pilot were then automated out of the picture. The primary role of "the pilot" however remained the same - direct responsibility for all flight path inputs. Almost universally the pilot with **overall responsibility** for the flight is also called the "pilot *flying*", *"Handling* pilot", or some such terminology. If a First Officer is acting as Pilot-in-Command Under Supervision, then he or she usually becomes the "pilot flying": command - being "in charge" - is regarded as fundamentally inseparable from direct Control.

The role of Crew Resource Management.

More up-to-date thinking has given us much improved facilities on the aircraft, and Crew Resource Management (CRM). At the very least, CRM is intended to ensure that the Pilot receives information and advice not only from the other crew members, but also from external sources. A fundamental element will also be that wherever possible, adherence to SOPs will enhance safety. CRM training may also incorporate advice to **delegate the aircraft handling functions under many circumstances**, as well as utilising as much as possible of the aircraft avionics. This will often result in a conflict: SOPs say that handling should be done by the Pilot in Charge (the Pilot Flying), but good CRM indicates it should be delegated to the other pilot as a lower priority task. At the same time, of course, the CRM training emphasises the need to stick to SOPs. A question which is often lacking in CRM courses is this: how do you determine when the situation has become serious enough to warrant this delegation? When should the basic SOP allocation of duties be abandoned because it does not give the pilot-in-charge the opportunity to resolve the bigger problems?

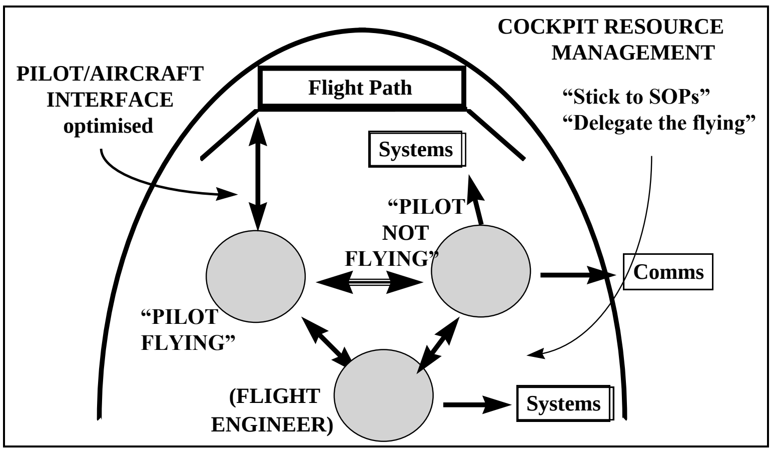

Figure 3: modern "assisted" multi-crew operation

In many of the events used as examples for CRM training, a fairly dramatic event is used to illustrate the benefits of what is being advocated - a good example perhaps being the UAL DC10 accident at Sioux City. However, in many real world accident and incident scenarios, it is evident that a gradual breakdown of ability to "see the overall picture" has occurred as successive minor events pile up, frequently overwhelming the pilot's ability to determine that a "break point" has been reached where this transfer (and departure from the **basic** SOP) has really become essential.

To protect against this situation it would be necessary to have the delegation achieved BEFORE the degradation sequence starts, and the inevitable deterioration of judgement under pressure occurs. In fact of course this is eminently logical. If delegation provides a better way of managing situations which **have become** hazardous, isn't it equally a better way of managing situations **before** they become hazardous? Incorporate delegation into the SOP, and there is no requirement to deviate from the SOPs to achieve good CRM. (See also Appendix 5, which contains a more detailed analysis of this problem, based on a fictional accident scenario.)

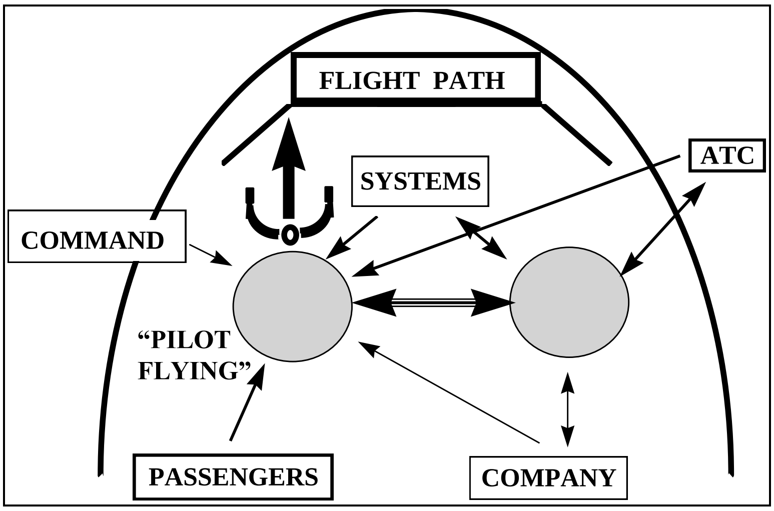

Figure 4: Basic modern two-crew allocation of duties.

So in the standard modern two-person flight deck default[xiv] SOPs, the Pilot, (usually in the left seat) handles the aircraft, responds to inputs from ATC, from the company, and from the systems, and functions as the overall commander. The Co-pilot (usually in the right seat) handles communication and system operations. The Co-pilot has two basic functions: most of the time, to **assist** the Pilot in achieving his intentions, but also monitoring, correcting, and if necessary **preventing** the Pilot doing what he intends. This is a pretty standard basic airline allocation of duties.

This arrangement can be analysed from two different perspectives. One is a "mechanistic" approach, looking at it from a system design perspective, in terms of crew members as components with interconnections and reliability criteria. The second could be called a "humanistic" approach, with a social interactions perspective, dealing with relationships and perceptions, society and culture. However, both approaches point to same conclusion: **basic crew co-ordination SOP concepts must be changed to meet current safety challenges**.

[xiv] The initial assumption in almost all airline procedures must be that the pilot designated as the Captain will be the "Pilot-in-charge". Widely varying differences then occur which determine whether on any particular occasion he actually will act in that capacity. This issue of "co-pilot flying", "leg and leg operation", "First Officer handling", "training requirements", etc., is complex and frequently confuses the issue. Individuals tend to assume that their particular norms in these matters are universal, when in fact they are not. For this reason these issues are dealt with in an Appendix. However, the justification for stating that the arrangement described is the general default assumption is that it is difficult if not impossible to envisage a situation where any other pilot could act as pilot-in-charge without the consent of the assigned aircraft commander, i.e. **demand** to be "given the leg". In other words, the assigned Captain will always be the pilot in charge **unless he agrees otherwise**.

Ranks, roles, and functions - making clear what we mean.

"When I use a word," Humpty Dumpty said in rather a scornful tone "it means just what I choose it to mean - neither more nor less." - *Lewis Carroll*

Firstly however it is necessary to clarify some basic terminology issues. In the airline industry some basic words are often assumed to have a common meaning, when in fact there are subtle but significant differences in interpretation which depend on the speaker's or writer's personal background. The terms "Captain," "Pilot," "Pilot Flying (PF)", or "First Officer", "Co-pilot" and "Pilot not Flying (PNF)" have common meanings at some times, and different meanings at others, but exactly **when** the meaning changes varies enormously within the industry. Some airlines mix crew rank, role and function almost indiscriminately - the wording of their SOPs may generate a basic assumption that "Captain = pilot in charge = pilot flying"[xv]. (It will be seen in Appendix 4 that this also affects the way that "First Officers' sectors" are dealt with).

While airlines may actually interchange these terms differently, individual pilots tend to assume that their own (and their airline's) interpretation of the terms is in fact also that used by everyone else. A rational discussion of crew procedures cannot be conducted without a clear mutual understanding what these terms actually mean. So at least for this discussion, the following concepts are used, and placed in the context of a time period when two or more individuals are flying together as a single crew, i.e. for a flying duty period, which may comprise more than one flight.

- The terms "Captain" and "First Officer" actually denote the **rank** which an individual holds within the airline. **Rank cannot change during the course of a flying duty period:** if you are a Captain when you sign in for a duty, you will expect to sign out as one as well.

- The terms "Pilot" and "Co-pilot" should really be used to indicate an individual's **role** in the operation**.** Generally the "Pilot" is the crew member regarded as being "in charge" of the flight and primarily responsible for its overall conduct and decision-making, whilst a "Co-pilot" occupies an essential but subsidiary role. Crew members may change **roles** during the course of a flying duty period, but generally they do **not change roles during the course of an individual flight**. For example, in typical "leg and leg flying", during a single flying duty period of one day with four sectors, each may act as "pilot-in-charge" for two sectors, and as "co-pilot" for two sectors. The role exchange lasts for units of one complete flight. In this discussion, the terms "P1" (first pilot or "pilot-in-charge" of a single flight) and "P2" (second pilot or co-pilot) will be used.

- The terms "Pilot Flying" (or "PF") and "Pilot not Flying" (or "PNF") should designate **tasks,** indicating which individual in a crew has the immediate responsibility for short term control of the aircraft flight path. **It is quite common for this to change during the course of an individual flight**. For example, the P1 (in charge) may ask the P2 (co-pilot) to take the controls whilst he examines the implications of a particular technical failure, or wants to discuss some aspect of operations with the airline's control centre or take a physiological break. Since both pilots are involved with a flying machine, however, for this discussion the terms "**handling** pilot (HP)" and "**non-handling** pilot (NHP)" will be used.

[xv] Internal inconsistencies often occur. An airline might state that its policy as to train Captains and First Officers to equal standards, to equalize skills by "leg and leg" flying, and to have the F/O do "all the Captain's tasks during his leg" - but then place restrictions on critical areas such as "only the Captain may abort a takeoff".

The reason for making these distinctions will be clear when it is realised that an identical division of physical activity in Standard Operating Procedures may be written down as allocating them to "Pilot Flying" and "Pilot not flying" in airline A, to Captain and First Officer in airline B, to Captain and Co-pilot in airline C, etc. Within each airline, all the pilots know what is meant, e.g. when a Captain may "be" a co-pilot, or a co-pilot a "pilot flying"; but these rules do not necessarily have any common meaning between airlines A, B, and C.

How reliable is our control system?

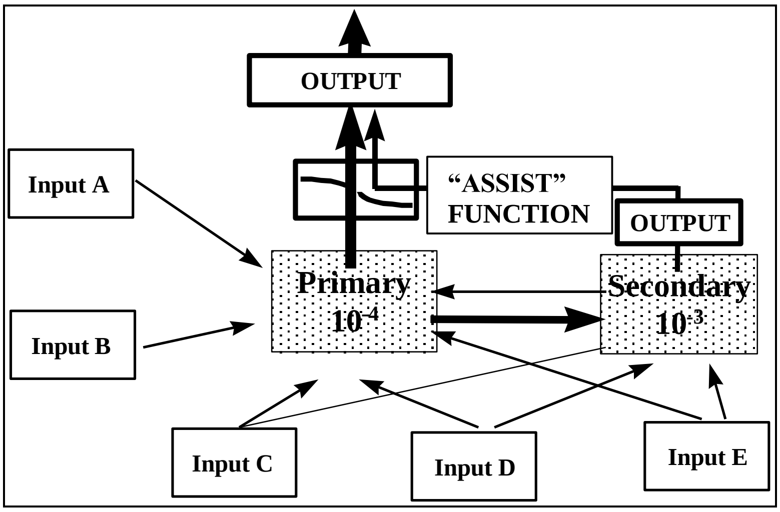

Figure 5: Control system in normal, "assist", mode

Envisage a system with the following characteristics. It has two control units with the same basic characteristics, except that the "primary" unit has more input parameters than the "secondary" (5 compared to 3); more output force or authority (as indicated by the thickness of the "output" line), and has a higher reliability (10^{-4} vs. 10^{-3}). The normal function of the secondary unit is to **add** its output to that of the primary controller. (Figure 5).

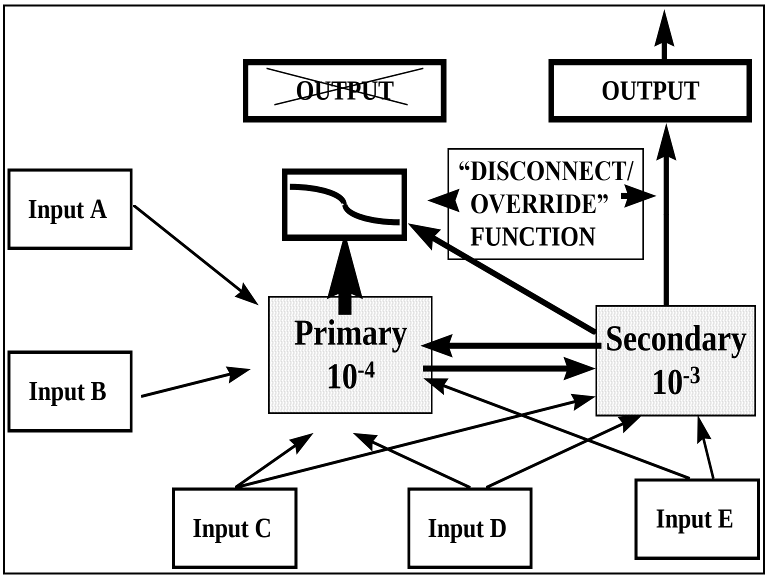

Figure 6: Control system in alternate, "over-ride", mode

The control system also has an alternate mode. (Figure 6). In this alternate mode, the secondary controller must detect and rectify faulty outputs from the primary, and if the fault continues, disconnect the primary system and take over with the correct output. But when we examine this, we can see that since the secondary unit has fewer inputs and is also less reliable than the primary, it is more likely to be in error if it computes a different output to the primary. It also has less output force to operate the "torque switch" and take over, if it has correctly detected a failure in the primary. Few engineers, and not many pilots, would see this as a 10^{-7} reliability system. A Failure Mode and Effects Analysis is likely to reject this system as inherently unsound.

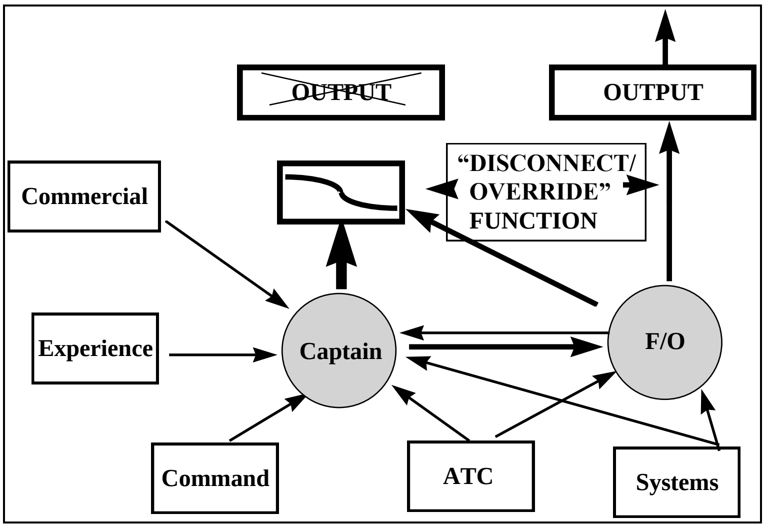

Figure 7: the crew as a control system?

However, substitute a standard airline crew, with typical SOPs, into this picture and what do you get? The (nominally) less capable and less powerful First Officer is charged with firstly **assisting** the Captain to achieve his objectives, whilst simultaneously monitoring them for correctness, and if necessary **preventing** him achieving them[xvi].

Much CRM training is about persuading individual pilots to overcome the fundamental and obvious weakness of this system, by educating them into changing their personal behaviour and social patterns. It would be more productive to redesign the system, rather than relying on achieving improvements in its components. The effectiveness of CRM training is greatly diminished by our collective failure to recognise this fact, and the internal conflicts it generates, and it appears that many crew members in fact subconsciously recognise that there are inconsistencies in what they are being told, reducing the effectiveness of this element of CRM training.

That leads us to the alternative "humanistic" way of approaching the issue, for those who don't like the idea of comparing a human system to a mechanical one. "Failure to adhere to SOPs" is the most common element in crew error accident causes. Initially it usually results from either inadequate reception of available information, or some misinterpretation of information which *has* been received. The psychological factors which lead pilots into either of these conditions in situations of stress and high workload are well known. If either results in an inappropriate response by the pilot flying, it is directly converted into action which affects the aircraft situation and/or flight path.

The problem then becomes one of error **recognition and recovery**, and the longer the time taken for this to occur the less likely it is that it will be successful. Recognition and recovery are critical to achieving error tolerance, and anything which inhibits error recognition and recovery is a major safety hazard. Almost all SOPs therefore also incorporate statements requiring the non-handling pilot to intervene to prevent a hazardous action by the handling pilot being continued. Failure to do so is another non-adherence to the SOP - a monitoring or challenging failure.

The fundamental characteristic of most SOPs is that they allocate the initiative for all action to the pilot in charge, nominally the Captain. The task of error recognition and correction is allocated to a subordinate. The degree to which the subordinate is able to achieve such corrections is driven by his or her ability to overcome the difference in authority between the parties, which is sometimes called the "Cross-cockpit Authority Gradient". Most

[xvi] For a more detailed analysis, see "Allocation of Flight Crew Duties" by Capt. David Quilley, formerly Chief Inspector of Flight Operations for the United Kingdom Civil Aviation Authority, and previously a senior British Airways Training Captain.

CRM training includes a significant element which attempts to modify individual behaviour, for example to overcome inhibitions about speaking out when mistakes are noticed. However, admirable as this idea may be, in many areas of the world it is just not going to achieve the order-of-magnitude improvement needed, especially if the basic SOP structural philosophy actually works against it[xvii]. Even in the USA, some years ago an NTSB report noted “It is extremely difficult for crew members to challenge a captain even when the captain offers a threat to the safety of the flight. The concept of command authority and its inviolate nature, except in the case of incapacitation, has become a practice without exception”[xviii].

The cultural conflict.

In the flight deck (just as elsewhere) we are all encumbered with certain habits and assumptions which can collectively be labelled as “culture”[xix], which includes professional, company and national or social aspects. Because of the single-pilot design of most non-transport aircraft, the professional culture of all pilots already tends heavily toward an individualistic attitude, which CRM training generally attempts to minimise. However, a lot of this aspect of CRM work seems also to be biased to a particular, idealised Western cultural and social model, which is entirely inappropriate for many airlines. This issue of cultural differences has now become a respectable subject to mention, and not before time[xx]. Much emphasis in many CRM courses is placed on achieving two-way communication, responsiveness to inputs from junior crew members, and the need for initiative from those junior crew members. In practice there is often resistance to some aspects of this by non-US crews - and sometimes by US crews, too. We have to find a way to build on cultural strengths to reinforce good CRM, not have CRM and cultural factors oppose each other[xxi].

The ideal to which many CRM courses seem to aspire is a sort of "Good Buddies" concept. This is really an American social ideal based primarily on strong respect for the individual. Its characteristics include emphasising that all individuals are equally valuable; that teamwork needs a leader to be "first amongst equals"; and it incorporates full respect for the inputs of all members of the team, regardless of their status. In the ideal world of this concept, a flight crew would consist of experienced people who can respect and relate to each other as equals, taking it in turns to assist each other. **Individual satisfaction** is critically important. Expertise in piloting – i.e. control manipulation - is viewed as the most satisfying

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[xvii] Bob Helmreich, one of the world’s leading CRM experts, writes that “the optimal crew would be strongly oriented towards teamwork and a consultative style of leadership in which junior officers felt encouraged to speak up to share information and advocate alternative courses of action. The most effective crew would adhere to SOPs but could still use their judgement to deviate from rules in the interest of safety. The challenge for CRM developers is to harmonise the training with local conditions and culture”. (Scientific American, May 1997, p44.) An equally big challenge may be to recognise that this harmonisation may require the Western trainers to modify their assumptions about the best way to achieve results in societies where “consultative leadership style” is a very unfamiliar concept.

[xviii] NTSB report into accident to JAL8054, January 1977

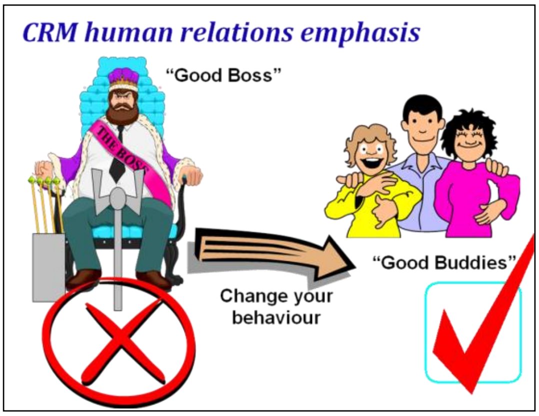
[xix] For a layman’s overview of this subject, see “Riding the Waves of Culture” by Fons Trompenaars.

[xx] The need to accommodate cultural differences was recognised in comments by Pierre Jeanniott of IATA at a Transport Canada Seminar in 1996. Another good commentary can be found in the Flight International editorial “Forbidden Factor”, April 24 1996.

[xxi] According to Helmreich and Merritt, only 36% of pilots from one national group agreed that crew members should express concerns about the safety of a flight, whilst in another survey about 5% of pilots not only reject the lessons of CRM, but some actually have worse CRM attitudes after training. (Scientific American, May 1997, pp.44-45).

attainment, and the best collective result is obtained as a consequence of all individuals being satisfied[xxii].

However, most other societies have an ideal which is different to some extent. The opposite extreme can perhaps be described in an equally over-simplistic way by an "Oriental" model which I'll call the "Good Boss" concept. Its characteristics might include the view that high rank and authority inherently endow opinions and actions with correctness; the views of the most skilled and experienced team member should be the most respected; good teamwork needs a strong, decisive leader; and the value of inputs is proportional to the importance of the team member. Being an expert pilot is viewed as the most prestigious attainment. In this culture, the ideal crew would have a highly skilled commander, accurately supported by qualified and obedient subordinates. **Group satisfaction** is critically important, and an individual is satisfied best as a consequence of the group being satisfied – as opposed to the Western model, where group satisfaction springs from each individual being satisfied.



In these societies, respect for authority and conformity to group norms is seen as a very positive and beneficial thing[xxiii]. However, many Western aviation "experts" give the impression via their CRM advocacy, that it is a **hazard** in operating large aircraft. It seems both arrogant and counterproductive to tell people that if they want to fly safely, they need to change their entire social and cultural framework when they enter the cockpit. Would it not be better to find some way of changing the recommended methods of

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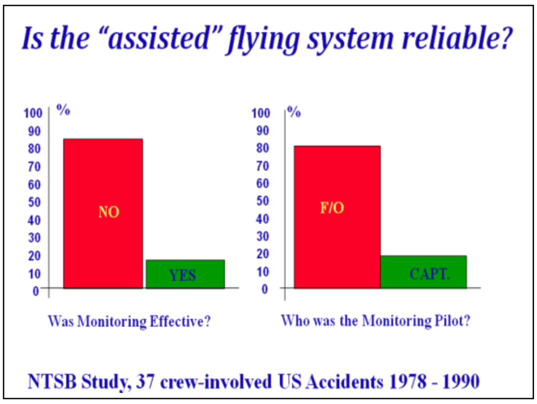
[xxii] The (fallacious) assumption that the "good buddies" concept is the "natural" ideal way of doing business is partly generated by purely economic factors in the USA. In North America not only are there large differences in pay between airlines generating movement from Captain to First Officer positions, but within many US airlines pilot pay is based mostly on aircraft type. This frequently results in First Officers (or even Second Officers or Flight Engineers) on one type being paid more than Captains on others, **within the same airline**. As a result it quite is natural for pilots in the course of a normal career to move several times between the ranks. For example, a First Officer might "bid down" to Second Officer on a larger and better paid type, or "bid up" to Captain but take a pay drop on a smaller type; and a Captain on a small type might bid to become First Officer on a larger one. Consequently differentiation by rank is relatively insignificant in the USA, and it is not too difficult for Captains and First Officers to regard each other as operationally equal in the way necessary for the "good buddies" concept to work.

However in many, if not the majority, of non-US airlines, this practice is not applicable. Many airlines find the US practice not to be cost effective because the savings achieved by differential salaries are more than outweighed by inefficiencies caused by frequent conversion training. In these airlines, pilots are assigned to aircraft types by other factors: pay levels may or may not be a factor. Promotion to Captain often then becomes a once-per-career step: failure to pass a lengthy and arduous "command course" is a significant and career-limiting event. As a result of these basically economic factors, it is harder to overcome rank issues, on the way to achieving the "good buddies" ideal, than it is in the USA. In one major European airline which was the subject of a merger, some of the Captains in one of the merged airlines were "displaced" as a result of their position on the new single seniority list. A number of these pilots resigned rather than be "downgraded" to Senior First Officer rank, despite the fact that financially their pay was "protected" to at least as much as, if not more than their previous Captain pay.

[xxiii] See for example "Optimum Culture in the Cockpit" by Capt. Hisaki Yamamori, Japan Air Lines, NASA Conference Publication 2455 for a view of these differences.

working to take advantage of those cultural strengths, rather than attempting to undermine them?[xxiv] What I am going to suggest not only does just that, but it also simultaneously reinforces the Western, "ideal equals", techniques.

How well are we doing?



Before looking in detail at a different concept, however, we have to ask whether, despite these "theoretical" defects, the present system does actually work adequately. In fact, many accident reports tell the same story, but their analysis does not spell out the issue clearly enough. In the NTSB study[xxv] of 47 US crew-related accidents referred to earlier, 84% of the accidents involved a "monitoring or challenging" failure. In almost the same percentage, it was the lower authority unit - the First Officer - which failed to make the switch from assist to over-ride. This data makes two things clear: failures in the monitoring and challenging process are a major problem, and rank, role and function (which differentiate Captains and First Officers) play a significant part. Bear in mind that this is the result in the USA, which already has the most favourable social, cultural and economic climate for CRM and other forms of advanced training, and in which the "good buddies" concept is most likely to bear fruit. It also already has a far better accident record than most of the world[xxvi]. We have no reason to assume that different (certainly not better) results will be obtained in other global regions.

Considerations in SOP design.

So it appears that whether you approach the issue of crew co-ordination SOPs from the mechanistic or the humanistic view, the current concept must be modified to achieve a significant improvement in reliability of the crew, as opposed to the pilot. How can we modify procedures to achieve our objectives? A "systems engineering" approach might include the following considerations.

- SOPs, interpreted and modified where necessary by experience and discretion, give crews guidance as to what action to take. More comprehensive or detailed guidance may in fact now be essential: the relatively low exposure of many crew members to many historic

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[xxiv] "Forbidden Factor" - Flight Editorial, ibid. "There is a dangerous assumption that, just because the highly developed "Western" world generally has the lowest accident rates, all "Western" methods are automatically the best available. It may just be that the developed, technologically advanced, nations have been flying intensively for a lot longer and have had time to work out routines which suit them. These routines may not be the best for non Western cultures".

[xxv]NTSB Special Study SS - 94/01, ibid.

[xxvi] Although CRM training definitely has had a measurable effect in the USA over this period, it is not enough to achieve the massive improvement needed. For example, Bob Helmreich's data shows consistent improvement in briefings, conflict resolution, communication, decision making, planning etc., but the relative improvement is in ratings on a scale from 3.O to 3.5 over a period of 4 years ("Managing Human Error in Aviation", Scientific American May 1997, p42. Other authors such as Besco ("P.A.C.E : Integration of CRM with Operational Procedures", SAE G-10A Minutes, August 1996) illustrate the problem in a specifically US context. This latter study concludes that additional formalized intervention and callout procedures (amongst other things) are needed to integrate CRM more fully into routine operations.

types of operational problem in modern aircraft has reduced individual experience of them[xxvii], whilst technology has added new and more complex aircraft management issues.

- Determine what are the real "worst cases" from the perspective of normal operation, and structure the procedural philosophy to address them as the default operational situation. Just as we require an engineering and performance capability to handle an engine failure at V1 on **every** takeoff, we should require a crew capability to operate safely with all permitted combinations of circumstances. For example, we should assume there will be a crew with minimal experience encountering adverse weather - which is NOT necessarily very low visibility - on **every** flight. Then when those circumstances do not apply – which is the vast majority of occasions - there will be **additional** margins. Many SOPs currently expect the crew to apply additional, more conservative procedures in more demanding conditions. However when these have not been predicted, the crew may only become aware of them once it is too late to take the required precautions.

- Make any assumptions in the SOP as explicit as possible, to provide a framework within which that experience and discretion can be employed. Most airlines expect that if a Captain and a First Officer are scheduled to fly together, the Captain (who is by definition the Pilot in Command) will also act as pilot in charge (i.e. he will perform among other things the takeoff and landing) - unless, after considering all the circumstances on the day, he decides to allow the First Officer to act as pilot in charge (under his supervision). That is the assumption in this paper. Stating this can make it much easier to write a comprehensible procedure, without detracting from existing flexibility, since it makes the differentiation between rank, role, and function clearer. In the discussion that follows, it is assumed that the Captain has not "given" the F/O the leg, and is acting as the P1 or Pilot in Charge. This assumption in no way prohibits "leg and leg" flying, but for simplicity this issue is covered in Appendix 4.

- Design procedures to maximise the incentive to adhere to them, and minimise the opportunity for deliberate deviation from them.

- Ask if error **correction** is possible? If an error can be corrected after detection - and most can - then maximise the probability that it will be. If it can't, minimise the chance of it happening in the first place. There is little point in detecting an error if we do not then correct it. If it can be corrected, we should optimise the detection and correction process. That is what makes the system error tolerant.

The latter is critically important. If a particular error **cannot** be corrected, then minimising the probability of its initial occurrence means that the most skilled and reliable crew member should take that action. But if it can be corrected, which is in most cases, then from both a mechanistic and human perspective it means that the **higher authority person should SUPERVISE** rather than initiate an action. So where possible, we should separate the concept of command from the need for immediate physical control.

In practical terms, this implies that since there are very few irrevocable actions in normal operation, the majority of the routine flying tasks should *normally* be delegated. However, there are two decision/action areas which occur on every flight where, at the limit of the routine operational envelope, a mistake cannot be corrected and therefore should not be

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[xxvii] Technology has reduced exposure to systems and propulsion malfunction enormously. However some routine operational techniques are now relatively uncommon: correspondence in "Aviation Week" in the late Fall of 1997 following the Guam B747 accident showed a number of writers who considered a non-precision instrument approach to be so rare as to be virtually an emergency procedure in modern aircraft.

delegated by the pilot in charge. These are (1) a go or stop decision at V1 on takeoff, and (2) a land or go-around decision at DH/MDA in limiting visibility. The certification requirements of the aircraft itself ASSUME that a correct decision will be made in both these cases. There is no margin provided for an error to be detected, and the decision to go or stop, or to land or go around, to be reversed safely. The takeoff and landing involve "uncorrectable" decisions and actions, and should therefore be made by the P1 (pilot in charge): but other cruise, descent, approach, and missed approach phases, where errors can be corrected, should be flown by the P2, with the P1 acting as commander and supervisor.

A Crew Co-ordination SOP for the 21st century.

A basic operational procedure to minimise risk and optimise error detection and correction therefore sees the Pilot in Charge (P1) carrying out the takeoff (just as in conventional operation), but **delegating the en-route flying, and approach to the P2**, prior to making the landing. "Ownership" and command of the sector remains with the P1, even although the P2 may spend more time handling the controls, and it is important to emphasise this. Equally importantly, however, the P1 should not treat the P2 as a "human autopilot", and issue detailed instructions to him: the objective should be to maximise usage of the intelligence and skills of the P2.

The basic instruction given by the P1 should be, in essence, simply "take us to the destination in accordance with Standard Procedures." During the approach briefing prior to descent, the P1 might ask the P2 (amongst other things) "where do you plan to start the descent? How do you intend to set up the radio aids?" The obligation on the P2 is then to use his own skills and judgement to fly the mission, to the point where the P1 can make a satisfactory landing, and dealing with tactical issues as they arise, whilst bearing in mind that his actions and decisions are subject to the overall approval of the P1. The P1 needs to be satisfied that the plan is safe and sensible, and can make modifications if necessary, but the briefing process becomes far more interactive and team-oriented.

After performing the first critical **handling** function – the takeoff - the P1 then switches over to the more important **operational management** functions of command and communication, until again it is necessary to carry out the second critical handling function of the actual landing. Because the P1 is then responsible for most communication, the potential for interpretation errors in the information chain from external environment, to overall decision-maker and back, is also largely eliminated[xxviii]. Appendix 6 contains a tabular Specimen SOP Allocation of Duties.

Encountering un-forecast or unreported poor weather and other unusual problems are entirely foreseeable events in the long term for any airline, and the basic SOP should deal with them adequately. This is no more than a need for airline organisations to "think ahead" and anticipate problems, just as they advocate that individual pilots should "stay ahead of the airplane". Many airlines have already adopted the concept of delegating the approach handling in reported marginal weather or low visibility conditions, as is recommended by

[xxviii] Many accident reports cite breakdowns in the communication process from aircraft commander to ground and vice versa as significant causal factors. Some of these breakdowns are inevitably due to the need for the co-pilot to act as a "go-between", a factor which injects both time and interpretation issues into the link. A classic example may be the AVIANCA fuel starvation accident at New York JFK. Event 1 in Appendix 4 is a similar example where the commander unquestioningly accepted his First Officer's misinterpretation of the radio communication containing the assigned altitude.

ICAO's recent CFIT study[xxix]. To achieve the safety improvement needed for the future, it is simply necessary to extend this practice to become the "normal" way of operating, as opposed to a "special procedure" valuable only for unusual "low visibility" approaches[xxx], or for "problem situations" as suggested in CRM training.

Benefits in different cultures.

The impact of changing from the conventional "assisted piloting" to a "delegate and command" procedure has some subtle human relations benefits in each of the two cultural extremes described earlier. In strongly hierarchical cultures, it takes advantage of pre-existing attitudes, instead of attempting to undermine them. The F/O will now routinely fly the aircraft, as "the boss's deputy" - not only when allowed to be a "pretend boss" himself. Specifically, he has to conduct much of the flight in accordance with SOPs, to the boss's satisfaction, and particularly to fly the approach so that "the Boss" can make a good landing from it. Psychologically, he has a strong incentive to adhere to rules and procedures: if he does it wrong, the boss will not be happy, since the boss is going to take over later - not just in the event that it gets so screwed up as to be actually dangerous. Conversely, if he does a really good job, his performance will make the boss' task easier, reflecting well on the boss as well as on himself. Collective "team" performance is enhanced.

Meanwhile, the Captain's status is raised, because he is clearly seen to be supervising and commanding a subordinate, and will be taking over when the most skilled and demanding task has to be done. He becomes the "Master" or father figure who encourages and advises the more junior person, and as the skill of the junior pilots increases with experience, it reflects credit on the senior persons. Moreover, any reservations the Captain may have about the F/O's abilities (which would cause him to tend to disregard any criticism or correction *from* the F/O) are translated into additional safety margins: for example, in reviewing the F/O's proposed descent profile, he could add a few extra miles if he considers the plan to be optimistic. Many accidents appear to stem from the belief of the pilot flying that he can actually "still make it", when prudence suggests otherwise. Delegating the "important but routine" activity encourages both pilots to err on the side of caution, and helps eliminate complacency.

On the other hand, in cultures where "equal partners" is a widely accepted objective, it also tends to achieve exactly the kind of equalisation of skills necessary to reach the "Good Buddies" ideal. Again, please note that the suggestion that routine flying be delegated from the pilot to the co-pilot has no impact whatever on the concept of "First Officers sectors", other than to enhance their value. "Pilot-in-Command under Supervision" flying is essential to the long-term safety of the airline, not to its short-term safety. There is no change needed to an airline's policies on this matter solely as a result of changing the "basic" procedure. During an F/O's leg, the F/O would make the takeoff and landing and the Captain fly the en-route and arrival. (See Appendix 4 for a more detailed explanation of this surprisingly complex issue.)

[xxix] Recommendations to Operators, (g) (2): "use of the monitored approach procedure is recommended. The first officer flies the approach and where applicable the missed approach. The captain will monitor approach progress and subsequently land the aircraft after obtaining sufficient visual reference."

[xxx] The basic problem with having a special procedure for "poor weather" is that (a) it assumes that poor weather is predictable when in fact forecasting and reporting are inexact sciences , and (b) it results in low levels of practice if the operating environment is **generally** benign. The hazardous case is rarely encountered, and when it is the crew may be ill-prepared to meet it. If on the other hand the assumption is made that all operations will encounter "poor weather", then fortuitous good conditions provide extra margins of safety.

Imagine a Captain who keeps all the takeoffs and landings to himself: he will now end up losing out on routine flying - but his F/Os will become extremely skilled, especially at instrument approaches. With conventional “assisted” procedures, such Captains become more practised at **all** flying tasks, at the expense of their junior colleagues. These Captains’ selfishness causes their F/Os’ skills to decline - which will also make them even less likely to respect the F/Os’ inputs when they are most needed, whilst the F/Os become less qualified to make effective inputs. In practice, the need to maintain a balance of skills will cause the most egotistic Captains (of whom we still have some) to become more even-handed, because otherwise their own skills will degrade. Again, it should not be concluded from anything said so far that the “delegation” concept requires that Captains should **always** do the takeoff and landing, and First Officers all the other flying, any more than current basic SOPs require Captains to do all the takeoffs and landings as well as everything in between.

Where’s the data?

Both the “mechanistic” and “human” arguments given here may be regarded as interesting but hypothetical: data is needed for the argument to be convincing. There is a significant body of experimental data[xxxi] which shows the benefits of delegation of flying tasks in non-normal situations, and this is generally accepted as part of the core of CRM training. Most authorities on low visibility operations also accept that there are severe physiological limitations on the ability of a pilot to make simultaneous use of both instrument and marginal visual cues[xxxii], and strongly encourage delegation of the flying tasks either to the other pilot, the autopilot, or both, until a clear and unambiguous decision can be made that adequate visual reference has been achieved[xxxiii]. However, there has until now been little real-world data published to support the clear theoretical benefits of making this the normal practice. Some comparative figures do exist however, from what was in many ways an unrecognised “experiment” performed in normal operations some years ago.

During this period, a major international airline had two different, autonomous operations, one using the conventional “assisted piloting” philosophy, and the other using the maximum “delegated piloting” philosophy. The initial selection criteria, the educational, licensing and training standards, and the cultural background of all the pilots was identical, and the two operations shared a single very comprehensive incident reporting and analysis organisation. Both operations involved primarily second generation jets including narrow and wide-body types, and although no “glass cockpit” aircraft were included, a significant amount of flying was on sophisticated types operating routinely to Cat 3 minima. The only other significant difference was in average sector length - one was mostly an intercontinental operation with a 4 hour average sector length, the other mostly an international and domestic

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[xxxi] e.g. from NASA trials in the late 1970s onwards, reported in NASA Ames Research Centre Publication 2120 “Resource Management on the Flight Deck”, etc.

[xxxii] Numerous studies by for example the UK Blind Landing Experimental Unit, the US Air Force Instrument Pilot Instructors School, NASA, the FAA Test Center at Oklahoma City etc., show that it is extremely difficult to adjust to simultaneous usage of internal instrument and external visual cues in poor visibility. Similarly, there is strong evidence to indicate while that the actual visual cues available at Decision Height in minimum visibility may be sufficient to judge the aircraft’s flight path in the longitudinal plane, they do not provide adequate information to assess and correct the flight path in the vertical plane.

[xxxiii] A specific recent example is the ICAO CFIT Task Force recommendation.

operation of 1.2 hour average sectors. A total of some 2.8m. flying hours and 1.53m. sectors were examined.

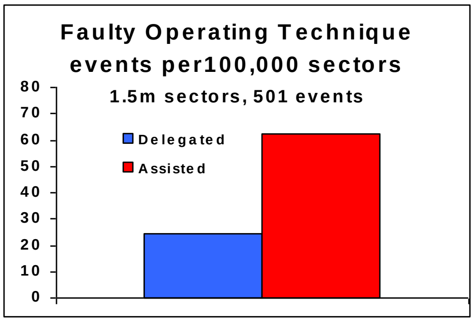

Figure 8

A basic item recorded by the airline's safety department was the occurrence of events attributed to "faulty operating technique": in other words, accidents or incidents due to crew errors which went uncorrected. Over a 7-year period encompassing over 1.5 million operations, the rate at which these occurred was almost three times greater in the conventional "assisted" operation than in the "delegated" one. (Figure 9)

Whilst the two operations were mostly with different aircraft types, as well as different average sector lengths, which may have skewed the statistics, there was one common type, operating similar medium to long-haul routes with identical sector lengths. Even with this much smaller sample size, the difference was still marked. Over a six year period the average faulty operating technique rate error rate for "conventional" operation was 120% of the overall type average, compared with only 70% for the "delegated" operation.

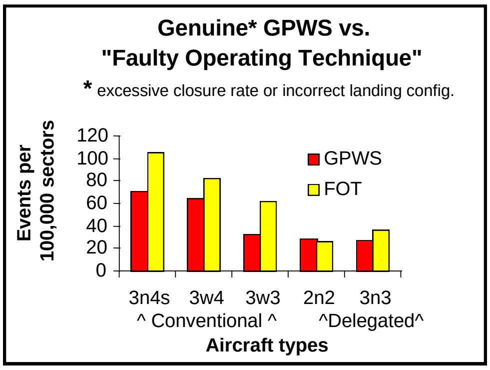

Figure 9

In these operations, "Faulty Operating Technique" encompassed all kinds of crew errors of varying degrees of significance, and in all flight phases. It does appear that there is a reasonable correlation between the occurrence of these crew error incidents of all types, and the more specific and highly hazardous events of Controlled Flight Towards Terrain. Fig. 10 shows data for 3 years operation of GPWS equipped types (covering about ½ million sectors and over 150 genuine GPWS events and all "faulty operating technique" events is shown in Figure 10. (Nb. The "aircraft type" identifiers refer to engine and crew numbers and body width class characteristics and are not individual a/c types: they are to show the relationship between overall crew errors and CFIT errors.)

A consequence of the "delegated" concept is that by separating responsibility for handling the approach from that of the landing, it is possible to minimise many of the physiological and psychological problems which arise when one individual is forced to make a transition from instrument information to external visual cues. There is a great deal of temptation to make this transition much earlier than is actually necessary, and replace accurate and valid instrument data with much more compelling (but potentially misleading) external cues. The problems associated with this transition when weather conditions are close to minima are well known, and are the fundamental reason for the recommendation by ICAO that the "monitored approach" be used for such operations. However, another classic situation where this occurs involves abandoning an instrument approach in favour of a visual one, and landing on the wrong runway or even at the wrong airport when a similarly oriented runway is located fairly close to the proper destination - events which occur with embarrassing frequency.

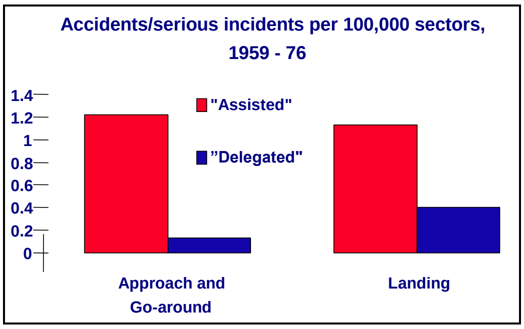

Figure 10

A different study over a much longer and earlier period, but concentrating on the approach and landing phase only, showed that for uncorrected major deviations from a flight path which **could** have been flown correctly by instrument information alone i.e. gross deviations prior to Decision Height (DH) or Minimum Descent Altitude (MDA), the incident/accident rate difference between the "conventional" and "delegated" concepts increased to some 9 to 1. This includes events of gross deviations during descent such as impact with terrain, and landing at the wrong airport. As might be expected, there was a much smaller difference in the rate of events during the actual landing phase (i.e. after passing DH/MDA), when differences in the procedures was minimal. Various arguments exist against concluding that crew procedures played any part in generating the differences in the event rates shown in all these charts, but in this author's view they collapse under investigation, for reasons which for simplicity are discussed in Appendix 2.

Where do we go from here?

Summarising everything said so far, it becomes clear that:

- it is imperative that we make a significant reduction in collective crew errors.
- a decade or more of attempts to improve individual crew performance has not achieved the required result.
- an "engineering" analysis of conventional crew operations shows they cannot achieve the desired reliability because subordinate crew members cannot be relied on to switch from a "help" to an "oppose" mode when necessary.
- a "humanistic" analysis also indicates that this kind of failure is inherent in the culture of most societies.
- actual NTSB data on airline accidents, as well as much anecdotal and other evidence, indicates that the breakdown of crew procedures which require co-pilots to make a "mode switch" from "assist" to "prevent" is in fact a major factor in those accidents.
- an alternative method of operation is possible and should in theory be more reliable from both perspectives.
- the only comparative data available indicates that the alternative does indeed produce significantly better results.
- a significant part of that alternative method is specifically recommended in the ICAO CFIT study.
- the alternative method incorporates one of the fundamental problem-solving tools recommended in most CRM training.

Given all those facts, there is a clear and unarguable case for the industry to make changes which will incorporate the concept of delegation of routine non-critical flying tasks into normal operating procedures for transports with a minimum crew of two pilots.

What then are the obstacles to introducing a change which has the ability to achieve the order-of-magnitude safety improvement needed? They can politely be called "natural conservatism"; a less kind description would be "lack of professionalism in airline management, and immaturity in the airline pilot community". The objections to changing are almost always emotional. People are concerned that the effect will be less "satisfying" flying;

that traditions are being abandoned; that accepting a different way of working is somehow an admission of earlier inadequacy, or indicative of surrender to an alien, “not invented here”, philosophy. They overlook the fact that our primary objective is to convey passengers with the maximum safety we can, and at present we are failing to do this.

If you have been sent this document and read as far as this, then I know that you personally have some significant responsibility and influence over the management of flight operations. My challenge now is this: unless you can prove that the arguments wrong, you have no option but to start changing the way that you recommend that airline pilots work. You cannot sit back and say “this does not involve my operation”. Pilots have been lectured for years about complacency, and the need to change their behaviour patterns, to be receptive to new ideas, and to put rational judgement of safety ahead of personal prejudices and concerns. If you neither accept nor refute the logic in this paper, but ignore it and just carry on as before, then the complacency which causes accidents is YOURS, not that of the line pilots actually involved. “Cockpit-caused” accidents will continue at their present rate, and you personally will bear some of the responsibility for them.

An implementation strategy to reduce the “Cockpit-caused” accident rate.

Aircraft Manufacturers. Many airlines rely heavily on manufacturers recommendations for all crew procedures. It is common for airlines to simply take the manufacturer’s Flight Crew Operating Manual or equivalent and simply incorporate it unchanged as the operations manual. The basic FCOM however is really intended as a set of instructions on “how to make the aircraft function”. It is **not** guidance as to how best to make the aircraft fit into the operational environment. Much resistance to this new concept is justified by statements to the effect that “it’s not recommended by the manufacturer, so it’s not the way the manufacturer intended the aircraft to be flown, so it can’t be right”. In parallel with the “how to make it work” manual, manufacturers must start to advocate delegated flying procedures for routine line operations. It is not enough to shrug your shoulders and say “it’s up to the airlines”. **The manufacturer’s name and reputation are associated with the catastrophe.**

Regulators must recognise that multi-crew transport operations *are different* to single-crew operations. They must devise recurrent training and checking requirements which do not sacrifice crew-oriented activity in order to emphasise inappropriate single-pilot criteria - not a difficult task, but one which requires a little imagination.

Pilots and pilot organisations must be open-minded about evaluating new ideas, and not insist on retaining traditions based on outmoded aircraft characteristics. They need to examine fact, data, and logic and not react too hastily to under-informed opinion and rumour.

And most importantly, **management pilots** must take time out to evaluate the lessons of past accidents and incidents, in order to eliminate their causes, not their symptoms. Changing what you tell your pilots to do is not an admission of being “wrong” but demonstrates leadership by showing an ability to learn.

It would be foolish to claim that any single idea can totally eliminate accidents caused by crew error, but adoption by the airline industry of the “delegated flying” SOP outlined in this paper has the potential to achieve the large reduction in the “crew-caused” accident rate we urgently need. The cost of doing so is minimal. No new equipment is needed, on the ground or in the air. **This is not an option that we can afford to turn down.** Those airlines which already have adopted some elements of the procedure will see reductions in the cost and an increase in effectiveness of their existing training, as their operations are consolidated in a logically consistent philosophy. Others have the opportunity to move into a more appropriate way of operating for the next century with a single executive level decision. **The time has come for airline flight operations to be brought up to date. We cannot wait for improvements to individuals, equipment, or facilities, to solve our problems: for the most part, the solution lies in our own hands. It is time to implement it.**

Steve Last

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Appendix 1: Common objections to the concept.

Arguments against new ideas generally pass through three distinct stages, from "it's not true" to "well, it may be true but it's not important" to "it's true and it's important, but it's not new - we knew it all along." - UNPOPULAR WISDOM.

- "Incidents and accidents basically arise from individuals failing to perform as needed. We just need to weed out or improve the substandard ones". *Unfortunately, **anyone** can be sub-standard on occasion. In every accident, the people involved had previously been assessed as reaching an acceptable standard by those responsible for such assessment. We cannot afford to detect sub-standard individuals by hindsight after an event. The problem is not identifying individual "bad apples" in a barrel - it is that the barrel can leak, allowing vulnerable "good" apples to "go bad".*

- "We can put more effort into training to a higher standard instead". *This requires time, money and motivation. The vast majority of crews already operate to standards much above the minimum. "More training" has been the approach for the last decade or more and has not achieved the objective. Applying even more resources is like trying to fill a crate of beer bottles through a fire hose - most of the beer will be wasted, even if you can get the financial resources to buy the pump and hose – not to mention all that beer.*

- "We have inexperienced co-pilots so the captains have to do most of the sectors. The more junior F/Os couldn't handle flying many of our more challenging approaches." *In that case it is very unlikely that they could properly monitor the captains on those same approaches anyway, and are most unlikely to be effective at correcting errors. In the most critical circumstances, your operation in fact is essentially a single pilot one.*

- "We encourage our Captains to get the F/Os to speak up". *Maybe so. However when faced with a difficult or deteriorating situation they will probably defer to the Captain's judgement. Almost the only thing you can actually **guarantee** is that your F/O is capable of meeting the demands of his licence, e.g. flying an instrument approach to DH/MDA and go-around. If you have them doing a lot of that they will very rapidly build up both skills and confidence, which will help them respond to the Captains' receptiveness.*

- "We only have very experienced crews, so we don't need to change anything". *You are very fortunate. However the record shows that errors still occur with the most experienced and skilled crews. Often very experienced crews are the ones who fall victim to complacency. Having someone else do a critical job for you can often make you more conservative about risks. Let your friend drive your brand new high powered sports car with you in the passenger seat - you will probably discourage him from taking some risks you might find acceptable if you were actually driving. And just because you haven't experienced a specific problem yet does not mean you will not tomorrow.*

- "We fly "leg and leg about" so the F/Os are doing half the flying anyway - if we continue to do that your suggestion couldn't have any impact, because we'd just reverse the occasions when each is flying." *A seductive but erroneous conclusion. See Appendix 4.*

- "This concept might have been a good idea when we had to fly a lot of manual approaches - now we have good autopilots which take the load instead". *It is true that the original "monitored approach" was conceived to deal with approach and visual transition problems in poor visibility, and that very low visibility operations have now become relatively much safer because of the development of autoland systems. Automation has solved one set of problems but given us some different ones. If automation had solved the basic* *operational management problems we would not have so many Committees, Steering Groups, Safety Seminars and Task Forces studying the human factors issues of aircraft automation. Automation is a tool, not a substitute for human intelligence: if and when we do make blunders, automation allows us to carry them out with a great deal of ease and precision. Delegating the routine flying to the co-pilot, and having him delegate the manipulation of the control surfaces to the automation, probably provides the optimum number of defences against errors being put into effect. However, anyone who believes that today's automation is a substitute for a second human brain is fooling himself.*

- "This is fine for a short-haul, high intensity operation, but in our long-haul environment we don't get enough handling practice anyway, so it wouldn't work for us". *Why not? The fundamental difference at the two ends of the spectrum is exposure rate: an ultra-long-haul crew may get only 5% of the practice of an ultra-short-haul crew. That is a function of the sector length and maximum possible flying hours, not of operational procedures - with long sectors you get little practice, however you do it. What can be altered is the balance between crew members, and delegation at least ensures that both pilots will have some "hands on" time on each flight. It is certainly also arguable that lack of practice makes errors more likely, and in that case reliable detection and correction become even more important.*

- "Yes, but in a long haul operation each crew is statistically less likely to experience poor weather or emergency situations where perhaps delegation could be useful." *Maybe so. However, when they do they will be faced with a correspondingly less familiar and more stressful and error-inducing situation. They still need error protection.*

- "But we do advocate delegation in those circumstances." *So now you want them to deal with unusual or more challenging situations by using a set of procedures which they're not really familiar with, practised at, or comfortable with?*

- "Changing control close to the ground is bound to be dangerous - the landing pilot has to get the feel of the aircraft above Decision Height". *There is no evidence that taking control at low altitude is inherently more risky than at any other altitude. If the P2 is using the autopilot then the trim characteristics are the same as if the P1 had been flying - the autopilot acts the same regardless of who's programming it. If you advocate leaving the autopilot engaged down to minimums in "conventional" operation in limiting conditions then you have already disproved the need to "get the feel of the controls" (which presumably means moving them to confirm aircraft reaction, and hence disturbing a stable approach).*

- "That might be true if the autopilot is engaged - what if you have to do it manually and you have an inexperienced First Officer who is having trouble getting it in trim?" *The implication of this is that your F/O is really below the necessary standard for line operation, since he can't fly the aircraft adequately. This might create a problem for the Captain in the short term. The airline's bigger problem though is that such an F/O would be most unlikely to be able to detect and correct any errors made by the Captain - again you really have a one-and-a-half crew operation. Give the F/Os practice and they will get very good very fast.*

Appendix 2: Common objections to the data.

- "The data is all very old. It's out of date and irrelevant - don't you have anything more recent ?" *It is true that it is old, however that does not make it "out of date" in the sense of irrelevant. Unfortunately in 1983 the data collection, analysis, and recording techniques were changed, and comparative data became much harder to obtain. Also, the two operations started to become merged so that the philosophical boundaries became blurred. The data is still relevant to the issue under discussion.*

- "No, it's not. The aircraft types are now quite different. We have much better automation which makes this irrelevant now." *Again, it is true that there are no "glass cockpit" types in the data, but a significant proportion of the flying was done on aircraft with sophisticated automation including Cat 3B capability. Most of the aircraft types have been replaced with glass cockpit types, which generally have better handling qualities and higher mechanical reliability. They require greater overall aircraft management skills, not greater control manipulation skills. Automation does simple tasks with great accuracy: it will do the wrong thing (and successive wrong things, if so instructed) with great accuracy. It can also tend to induce complacency. The concept that delegation of a task to an automatic device is largely equivalent to delegating it to another human ignores the fundamental fact that automation does not contain intelligence.*

- "Since 1980 we've put everybody through CRM and other courses, and improved the "assisted" procedures in detail with better call-outs etc. So comparing the two data sets for then doesn't tell you much about whether it would still be the same today." *Maybe so. However it's the only data available. The same improvements (CRM training, call-outs etc.) have also been made to the "delegated" operation. The absence of current data doesn't undermine the fundamental logic. The vast majority of operations still use the basic "assisted" concept, and still break down too often.*

- "None of those who investigated the "assisted" flying events came to the conclusion that changing the procedures as you suggest was a good idea - they were all due to other factors." *Not actually true - see Appendix 3. However it is true that those responsible for the procedures did not see any reason to change them, and it is questionable whether a scientific (as opposed to an opinion-based) analysis of the problems was ever made.*

- "The biggest factor is that the "assisted" flying was on intercontinental routes in much less benign environments than the "delegated", which was mostly done in Europe". *That depends what you call a "benign" environment. In fact the percentage exposure of intercontinental operations to the kind of adverse weather associated with many accidents is relatively low. A United Kingdom CAA Study of the long-haul operational environment (Airworthiness Technical Note 111, August 1974) shows that the probability of such aircraft encountering either visibility of less than 3km, or a crosswind of 20 kts., is of the order of 3%, i.e. for a typical long-haul pilot each might be encountered on only perhaps 1 or 2 occasions per year on average. Short-haul European operations encounter less benign weather with a far greater frequency. However it may be true that a higher percentage of long-haul operations are conducted closer to the performance margins of the aircraft - there is no data to substantiate this, however, nor to indicate that this was a relevant factor in the incidents themselves. Similarly, it is hard to find data to substantiate any claim that long-haul operations encounter poor ATC services, or inadequate landing aids, at a greater rate than short-haul ones do per se. In essence, this argument boils down to a statement that long-haul operation is simply inherently more risky. If this argument is used as a reason not to take* *action to reduce risk then the industry had better cease pressing for longer and longer range aircraft and insist on landing more frequently.*

- "But the major element in the long-haul environment is that crews are much more fatigued at the critical points in the flight". *This is actually another version of the previous argument. It is certainly the case that a higher proportion of the long-haul flights were probably conducted at unfavourable circadian rhythm times, and possibly with lower levels of alertness. However the shorthaul environment also contained fatiguing elements including night shift operations and lengthy high intensity duty periods. All of the operations covered were conducted under scheduling rules which were the subject of a union - management agreement, which itself was set within the limits of a regulatory regime which had been specifically established following a lengthy and detailed investigation commission into flight crew fatigue issues. This legislation established detailed requirements to address the subject of number and length of sectors, amount and quality of rest periods, acclimatisation to local time, etc., to minimise the effect of crew fatigue on flight safety. There was little sign at the time of a general concern amongst the pilot community that the lifestyle inherent in long-haul operation was in fact so adverse as to make crew errors due to fatigue a major concern. Consequently it is hard to see that these elements alone would account for the differences actually seen. On the other hand, it would seem sensible to recognize that since such factors might well render crews more susceptible to error, making the need for reliable error detection and correction even more apparent.*

Appendix 3: An airline case history - four CFIT "close calls".

A major airline experienced four near-disasters with Controlled Flight Towards Terrain over a period of some 23 years, with one particular type of aircraft. The basic SOP on this fleet was the "assisted flying" concept, and in each of the events the Captain was the pilot flying the aircraft. In each case a catastrophe was averted more by good fortune than anything else. These events are particularly interesting because they illustrate a number of common aspects to aircraft accidents, the organisational responses to them, and issues of entrenched airline "culture". Because they involved no immediate injuries or major damage, all the crews involved survived the events themselves, and thus were available to participate in the subsequent analysis.

Event No. 1

In 1974, a four engined wide-body descended to within 70 feet radio altitude of the ground almost 7 miles from a high altitude airport. During an ILS approach, being flown by the Captain in instrument conditions, an altitude below that of the airport was mistakenly dialled into the altitude select, and an attempt was made to descend to it. A go-around was initiated when the ground was sighted. This event was the subject of a full accident enquiry by the airline's State Accident Investigation organisation, which concluded that amongst other factors which included crew sickness (the First Officer had been taking medication which may have reduced his performance and alertness), the fundamental causes were that the Captain's planning and conduct of the approach gave himself and his crew too little time to monitor the progress of the flight properly. His overall supervision of the approach was adversely affected by his personal preoccupation with the control of the aircraft, and the system of monitoring used by the company (i.e. monitoring by the junior crew members) did not function properly at a time when the cockpit workload was high. Accordingly, the national Accident Investigation Board recommended that the company should **re-examine its allocation of crew duties and monitoring responsibilities during descent and approach, so as to enable the commander to exercise his supervisory function to greater effect.**

The airline's own conclusions however were that the fundamental problem lay with the individual crew members rather than with the procedures laid down - the "bad apple" was therefore removed from the barrel and the Captain left the company. At around this time the airline was involved in a rather acrimonious merger with another carrier which used the "delegated flying philosophy". The recommendation that the procedures be reviewed "to allow the Captain more opportunity to supervise" was seen in some quarters as an attempt to interfere in the internal airline negotiations over integrating the new merged airline, and the basic procedures remained unchanged.

Event No. 2

Eighteen months later in 1976, a four engine wide-body descended into treetops about two miles short of the runway during a non-precision approach in good visibility, and a go-around was made. Again, the event was the subject of a full accident enquiry by the airline's State Accident Investigation organisation, which concluded that this incident was primarily caused by a poorly planned and executed approach by the Captain, and inadequate monitoring of the aircraft flight path by the crew. Again it was recommended that the airline **re-examine its crew procedures to establish whether a reallocation of crew duties and monitoring responsibilities would permit a greater degree of supervision.** Once again this issue did not feature in the airline's internal recommendations; it was concluded that the fundamental problem lay with the poor quality of the individual crew members rather than with the procedures laid down. The "bad apples" were therefore removed from the barrel: the Captain left the company, the other crew members were disciplined, and the basic procedures remained unchanged.

During the merger-related negotiations the issue of SOPs was the subject of much heated discussion. At one stage this resulted in a high level management group submitting recommendations for unification across the airline based on "assisted flying", and abandonment of the "delegated flying" concept. This suggestion was eventually disregarded when it was shown that the recommendations had been made based on "evidence" in which the position of other airlines had been deliberately falsified to support it, one of a number of actions which caused the sole non-airline member of the group to refuse to sign the group's report. However, this set the tone for the airline over the next twenty years: with no single operational philosophy across the entire organisation, the credibility of its management in seeking to obtain adherence to its SOPs was damaged. What was unacceptable on some types of aircraft was perfectly normal on others.

Event No. 3

Thirteen years later, in 1989, a four engined wide body made a badly controlled low visibility approach at its home base airport. During a go around it descended to 75 feet radio altitude, in the vicinity of an airport hotel and other buildings which rose to 70 feet. Again, contributory factors included crew member sickness and experience levels. For various reasons the airline's State Accident Investigation organisation did not conduct an investigation: it was left to the airline itself. It is likely that given the circumstances which led to the event, an Accident Enquiry would have come to similar conclusions to that reached in the earlier events: that **poor overall supervision and monitoring had allowed an unsatisfactory approach to be continued to far too low an altitude.** Although a number of detail recommendations for changes were made, the fundamental conclusion was again that the problem lay with the poor quality of the individual crew members rather than with the basic procedures laid down. More "bad apples" were therefore again removed from the barrel: the Captain left the company, the other crew members were disciplined, and the basic procedures remained unchanged. Internal memoranda however noted that the State Accident Investigators' recommendation regarding crew procedures in Event 2 was never adopted, nor featured in the company's internal recommendations, and linkage of that accident to Event 3 could have proved embarrassing.

Following this event the Captain was charged with criminal negligence in endangering people in the aircraft and on the ground. It is indicative of the inadequacy of criminal proceedings to deal with complex technical safety matters of this kind that he was found guilty of endangering his passengers but not guilty of endangering people on the ground. The Captain was fined, lost his licence, and later committed suicide.

Event No. 4.

Early in 1997, a four-engine wide-body aircraft making a straight in ILS approach at night at an airport in a developing country failed to obtain the glideslope signal, but the Captain, having had visual contact with the ground, elected to continue using DME data for altitude guidance. Unfortunately, the data for the wrong DME facility was used, and as a result the aircraft descended to some 350 feet radio altitude about 6 miles short of the runway, when a go-around was initiated. The final result of the investigation into this event is not available at the time of writing, but three months later the fleet procedures were changed to bring them into line with those used on the other fleets in the airline, i.e. replacing "assisted" flying with the "delegated flying" concept for all approaches, and finally implementing the official recommendations arising from event 1 some 20 years earlier.

Lessons to learn?

Significant factors in these events appear to include these.

- In each event, all the information was available to the crew to have avoided the danger they encountered.
- In each event, an initially satisfactory situation deteriorated as a number of individually containable events compounded on top of each other.
- In each event, it is possible to see with hindsight that the overall situation awareness of the pilot in charge had suffered because of his need to concentrate on a subset of detailed, aircraft handling, tasks.
- In each event, the other crew members had reservations about what was being done, but did not act forcefully enough to change the course of events.

In the first three events a "satisfactory" outcome was regarded as the eviction from the community of individuals whom events had proven to be unsatisfactory. In the first three events the fleet's culture found it impossible to accept that it, as well as the individuals, could be at fault. The ability to deal with difficult situations was seen as a test of individual worth. All its members had, by definition, shown themselves to be "worthy" until the moment when they failed. The fact that individual failure might entail massive loss of life was not a consideration: it could always be avoided by ever more stringent "quality control". The organisation in fact exhibited all the "right stuff" individualistic characteristics of the pilot professional culture recognised by other researchers such as Merritt et al. Strenuous efforts are made in CRM training to change attitudes of Captains towards accepting that they might be wrong; yet the reluctance of those with authority over the fleet to accept the possibility they might not be right is simply the same problem on a larger scale.

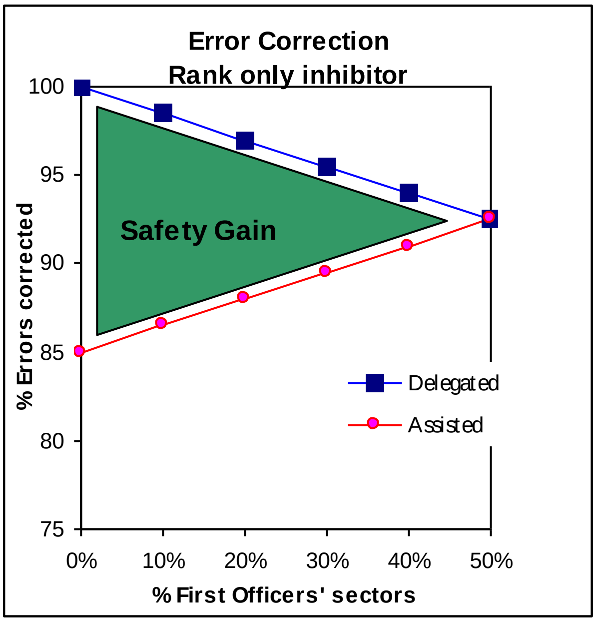
Appendix 4: "First Officers' Sectors."

The question of "First Officers' Sectors" is more complex than is generally realised, because there are so many different variations on the theme. This Appendix addresses it in the context of normal operations, i.e. with the aircraft in the physical condition in which the original decision was made by the Pilot in Command (i.e. the Captain), to allow the First Officer to act as Pilot-in-Command Under Supervision. It is assumed that in the event of a non-normal situation occurring, the first decision which will be made by the Captain is whether the problem is so significant that it requires that decision to be reversed. Consequently there is no discussion of non-normal operations under this heading: it remains the Captain's responsibility to determine whether the circumstances require him to resume the P1 role, or to continue to allow the First Officer to act as P1.

A very common objection to a revised SOP runs along the lines of "We agree that *in theory* you might get more effective error correction if the Captain is doing the correcting. But to get that benefit you'd have to have the Captains doing all the takeoffs and landings, and the F/Os doing all the rest of the flying. We want our F/Os to do takeoffs and landings as well, so we fly 'leg and leg about'. So in our case the F/Os are already doing half the flying anyway, and the Captains are already doing half the monitoring. We want to continue that policy, so your suggestion couldn't have any impact, because we'd just reverse most of the occasions when each is flying without changing the overall effectiveness."

The objection voiced above is highly seductive, because superficially it is self-evidently true. However, on examination it will be seen that it is true only if two specific conditions are met. They are (1) that **all** sectors are mandatorily allocated at random on a **50-50** basis between the two pilots, and (2) that the **only** factor in the cross-cockpit authority gradient which inhibits error correction is rank. In practice these conditions are never met, and under all actual circumstances there will be a benefit.

The basis of the objection can be illustrated like this. Take a theoretical operation which involves 100 sectors. Assume that it is flown by two-member crews of equal competence. Let's assume also that on every flight the pilot in charge does all the flying, and makes one significant mistake. Also assume that the "authority gradient" consists only of the difference in rank, and the Captains pick up and correct **all** errors made by the First Officers, but the F/Os only correct 85% of the Captains' errors. (These numbers are exaggerated, purely to illustrate the principle involved.) If the Captains fly all 100 sectors, they will make 100 errors, and 85 (85%) will be picked up, leaving 15 uncorrected ones.



Now assume the Captains "give away" 10 sectors. There will be 90 errors on "their" sectors, of which 85% will be corrected, whilst during the F/Os' 10 sectors there will be 10 errors, all of which will be corrected. Net result: 13.5 uncorrected errors. This will continue until at the point where 50% of the legs are "given away", and the uncorrected errors are down to 7.5, or 7.5 % of the total. This is the lower line on the graph. (.5 or half errors are of course purely a mathematical concept!)

Now take the situation where the flying which contains “correctable” errors (i.e. other than the actual takeoff and landing) is delegated. If the Captains “give away” no legs all the correctable errors are made by the F/Os, and all are corrected so there are: zero **un**corrected errors. Simple arithmetic shows that now the uncorrected error rate will increase until at 50% F/O sectors, again there are 75 uncorrected errors - the upper line on the graph. The argument then is clear: with 50-50 leg and leg flying the “delegated” concept produces no benefit because there are exactly the same number of uncorrected errors. **However, what is overlooked at this point is that 50% is the *maximum* number of legs which will ever be allocated to the F/Os, not the norm or average. For all values of less than 50% “First Officers’ sectors” (which is the practical range), there is always a benefit.**

Before going much further, we again need to examine some basic concepts. Just as there are many variations on terminology, there are many flavours of “First Officers’ sectors”, and each airline tends to think that its own is the basic recipe. Within each airline there are also different degrees of freedom to re-assign duties, some of which are company constrained, and some limited by regulation, so that not all flying by First Officers involves being “given the sector” - specific training requirements are one such area. For most airlines, however, it appears there are two different objectives which affect their policy. They are long-term and short-term safety impact, and most policies involve a trade-off between the two.

Take two extreme examples. One airline might believe that the optimum overall safety is achieved by making every flight as safe as it is possible to make it - maximising *individual flight* short-term safety. A consequence of this might be a decision that since the most skilled person in the crew is (at least nominally) the Captain, only Captains may make takeoffs and/or landings. This may ensure that each flight is as safe as it can be with that particular crew. A further consequence however would be that flights with newly promoted captains, who would have virtually no experience of takeoffs and landings, would be less safe than others.

Another airline might decide on a different way to maximise its long-term safety. It might require that all its Captains, including newly promoted ones, must have a significant amount of takeoff and landing experience in all conditions. Consequently, it requires its Captains to allocate 50% of the sectors to the First Officers, regardless of conditions, so they have that experience when promoted. It has applied the reverse short-term logic to achieve the same apparent objective - the safest operation in the long term.

In reality of course few if any airlines operate to these extreme policies, but most end up with rules which restrict or encourage Captains in using their discretion as to how much “additional margins” are needed to trade off the apparent safety gain from performing the takeoff and landing themselves, versus allowing a junior, less experienced and (theoretically at least) less skilled colleague do it. These limitations may range from “anything except Cat3B landings” to “only if the First Officer has been authorised and assessed as suitable for promotion”, but all recognise that in some conditions it is necessary to restrict First Officers sectors. Consequently, for practical purposes the actual number of legs given to F/Os will always fall in the range from nil to 50%, and it is hard to envisage an operation where it would rise above 50%. Similarly, the existence of any limitations means that the distribution of those sectors is not random, either. Consequently, **the first condition for the objection to be valid is not met: leg-and-leg flying does not result in a true 50/50 distribution, though it may result in a 50/50 distribution of the less risky operations.**

The other condition for the objection to be valid is that the only factor in the “cross-cockpit authority gradient” which inhibits error correction is rank. Rank was earlier defined as being a long-term position within the airline, which does not change in the course of a flying duty period. When a Captain and First Officer are flying together, however, the relative authority of each is not a simple “binary” one based on rank alone: all Captains are not identical, all F/Os are not identical, and the combinations are infinite. There are in fact several components to the “authority gradient” which include personal factors and role.

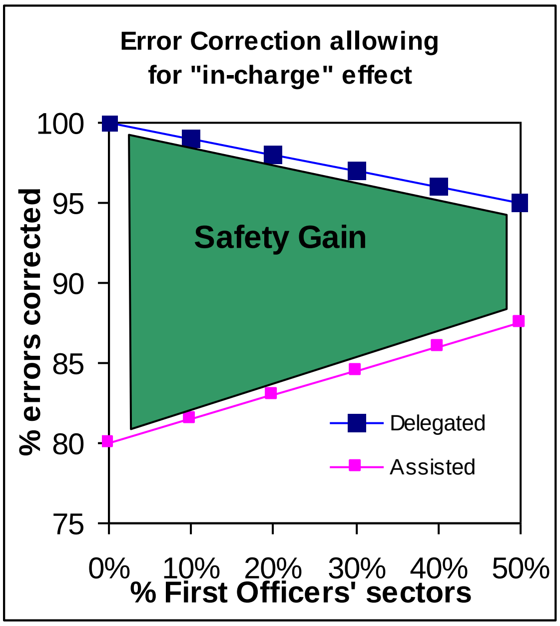
Personal factors include experience and interpersonal aspects. Two individuals could have joined an airline on the same day, and have identical skills and experience. The sole personal difference in fact between a Captain and his F/O could in fact be a seniority number allocated randomly which has resulted in one achieving promotion before the other. Rank as such is unlikely to be a very strong factor inhibiting the F/O from effective monitoring in normal operations. This pairing will in fact be quite close to the ideal “good buddies” crew. However, there is still even with this crew an inhibiting factor, which is the effect of role.

During the Captain’s sectors, his “good buddy” in the right hand seat may not be bothered by the difference in rank, but he may still be somewhat inhibited by the fact of the Captain being “in charge”. He knows that their relative skill levels are pretty finely balanced, and hence each party’s judgement may be equally valid, and he may thus be inclined not to vocalise criticisms. This factor becomes more significant however when the Captain gives his colleague the next sector: in effect, in giving the sector away, some of his authority of rank is also transferred. The Captain might not be inhibited from correcting a very inexperienced F/O, but he may be reluctant to interfere when he has already given permission to his friend to act as “the boss”. In reality, when a Captain “gives away” the sector, he also relinquishes an element (perhaps a very small element, but perceptible nevertheless) of his authority - the “in charge” element. From a human relations perspective it may be quite difficult to retrieve this. It will be embarrassing to both parties to have to reverse this decision, involving loss of face for the F/O and at least an internal admission by the Captain that he may also have misjudged the F/O’s skills. Consequently, the “cross-cockpit authority gradient” is made up of two elements - that of rank PLUS that of being “in charge”, and there is an inhibition on error *correction* (though perhaps not so much on detection) which is due to this.

This is in fact confirmed by the NTSB data which seems to show that although Captains have a much higher success rate at monitoring and challenging than F/Os, it is still nowhere near 100%. During a “Captain’s leg”, authority is composed of two elements - a “rank” element and a “role” (“in charge”) element, and during a First Officer’s leg, the F/O has a varying degree (based on experience and other interpersonal factors) of extra authority based on his “in charge” role. In both cases this authority acts as an inhibiting factor on the other pilot’s ability to correct errors.

Let us assume that this thesis is correct and that the “in charge” element does inhibit correction by a certain amount, compared to the 85% and 100% rates ascribed purely to the “rank” effect before. Let’s say that the effect is to change the correction rate by 5% of the errors - in other words, if you correct 5% more if you are in charge, and 5% less if you are not. (Once again, please note that these numbers are simply to illustrate the direction of the effect, and are not intended to be accurate). In the “assisted” flying operations, the F/O now corrects 80% of the Captain’s errors during Captains’ sectors and the Captains only correct 95% (instead of 100%) of errors during the F/Os’ sectors.

If the Captains fly all 100 sectors, they will make 100 errors, and 80 will be picked up, leaving 20 uncorrected ones. Now, say they “give away” 10 sectors. There will be 90 errors on “their” sectors, of which 80% will be corrected (leaving 18), whilst during the F/Os’ 100 sectors there will be 100 errors, 95 of which will be corrected. Net result: 18.5 uncorrected errors. This will continue until at the point where 50% of the legs are “given away” the uncorrected errors are down to 8.5. The possible range is between 12.5 and 20 uncorrected errors, or the correction rate is between 80% and 87.5%. (Lower line on graph).



Now take the situation where the flying which contains “correctable” errors (i.e. other than the actual takeoff and landing) is **delegated**. The Captains’ correction rate is already at 100%, but now the F/Os’ correction rate is increased by the 5% “in-charge role” factor to 90%. If the Captains “give away” no sectors, all the correctable errors are made by the F/Os, and all are corrected. Net result is as before, zero uncorrected errors. Now assume that the Captains give away 10 sectors. The result will be zero uncorrected errors during the 90 “Captains’ sectors”, and 10 errors during the F/Os’ sectors, of which 90% are corrected. Net result: 1 uncorrected error. At the 50-50 leg and leg flying level the there will be a total of 5 uncorrected errors, compared with 8.5 during “assisted” flying. The range is between zero and 5 (upper line on graph), compared to a range of 20 to 8.5.

In other words, if the authority gradient is due purely to RANK, there will be a benefit from “delegated” flying until the exact 50-50 leg-and-leg random distribution is reached, and then the two systems are equal. In any of the more likely situations, i.e. if there is less than 50-50 random allocation of flying, or any effect at all is allowed for the effect of the “in-charge” role, there will always be a benefit to delegation. **In practice, there is no way that changing to the delegated procedure will not provide a safety benefit, regardless of the airline’s policy in respect of First Officers’ sectors.**

Appendix 5: where did the situation get out of hand?

This Appendix describes and analyses a fictional accident scenario to show how conventional "assisted" crew co-ordination procedures and CRM training are not properly integrated to minimise the risk that a crew will be drawn into a situation where they are vulnerable to a variety of human factors failings. It is recognised that many of the detail aspects found in actual accidents are missing, but by creating a fictional event the possibility of making inaccurate and potentially offensive statements about actual events and individuals is eliminated. Most experienced pilots will have encountered some or all of the principal elements making up this story - they will just not have had them combine in this way. Please note that the diagram is only to illustrate the sequence of events.

Flight XXX99 - a typical CFIT disaster.

Flight XXX99 was a modern twin-engined, two-crew jet, operating a late evening service to Sommeton, a coastal airport in a developing country. Sommeton, elevation 420' a.m.s.l, has a single 2800m. runway 17/35 and is situated on the south side of a river estuary. The aircraft was fully serviceable but was approximately 90 minutes behind schedule because of a technical defect rectified prior to departure. The aircraft was scheduled to arrive at 2115 local, and depart at 2205, 55 minutes before Sommeton's 2300 noise curfew, which would be extended for a maximum of an hour in the event of delays. The crew were aware that the scheduled turn-around time was one hour, and also knew that the airline could routinely achieve a 35-minute turn-around if necessary. The crew were therefore anticipating that they would be arriving about 15 minutes before the curfew, and departing during the curfew extension period with about half an hour margin before complete closure.

The crew comprised a Captain aged 40 with a total of 9,000 hours, of which 4000 hours were on type, and who had considerable experience of operation into Sommeton. The First Officer was aged 30, with 5000 hours total time, but had only recently converted onto type and had not operated into Sommeton before.

The weather forecast was: wind 010/10, visibility 10 km. or more, cloud 1500'scattered, 4000' broken, temporarily visibility 3500m in haze, 700' broken. The NOTAMS included the following: Taxiway "C" closed between E and D. Glideslope ILS 17 unreliable. ILS-DME 17 u/s. Additional company briefings included: "Map shifts have been experienced during approaches at Sommeton. These are under investigation by the manufacturers. Until the causes are resolved, approaches must be conducted using raw data displays only."

The Company operations manual recommended SOPs based on the "assisted flying" philosophy that the Pilot-in-Charge should normally act as pilot flying. However, in recognition of the company's implementation of its CRM training it also contained the following advice: "In situations generating high workload, such as serious aircraft deficiencies, Captains should give consideration to delegating the flying to the co-pilot, in order to give maximum attention to the effect of such situations on the safety of the flight".

At 2217 the following ATIS information was received: "ATIS "C" at 2200 hrs, Runway 35 in use, wind 360 degrees, 9 kts, visibility 10km., cloud scattered 1800 feet, broken 4000 feet". At 2220, the Captain gave a descent briefing, which covered all standard items such as minimum safe altitudes and altimeter settings, brake and thrust reverser settings, airport information, etc. and included the following. “We’ll start descent from FL330 at TODES, which is 85 DME from STN. Descending initially at 290kt, then 250 kts. below 10,000, to cross STN at 7000. They don’t have radar here so we’ll be doing the procedural ILS for 35, but it looks like we should be able to go visual with any luck once we get down below 4000. We go outbound on the STN 198 Radial to 14DME, descending to 3000’ and reducing to 200kt. Once we start the inbound turn we can descend to 2200’, expecting to establish on the ILS at about 7 on the ILS DME, with 22 flap. Final flap is 27, to go down the glideslope at 6 DME. Minimums are 620 ft and 700m RVR, and the go-around is straight out to STN at 3000. I’ll use the autopilot all the way round onto final. V_{app} is 140, we’ll have 145 with that wind. Standard call-outs at all times. If you’re unhappy about anything don’t hesitate to say so”.

At 2222 Sommeton Centre cleared XXX99 to descend to FL290. R/T quality was poor. The First Officer read back “FL290” but the Captain selected FL250 in the altitude select. The voice recorder contains the following conversation:

Capt: OK, FL250 set

F/O: Uh…. I think that was 290.

Capt: No, I’m sure it was 250 - that’s where they usually hand us over.

F/O: OK - they could use a decent mike down there.

F/O: Umm… you know I’m sure he said two NINE zero….. I’d like to just check it.

Capt: OK…if you want to.

Sommeton confirmed FL 290.

Capt: Thanks for picking that up, I was sure he said twenty-five.

About a minute later the Captain remarked “looks like a nice night down there - I think that’s Capital City over there” (about thirty miles ahead). At 2226 XXX99 was handed off to Sommeton Approach which cleared it to FL160, and added “traffic is northbound, domestic departure off runway 17”.

At this point the Captain remarked “the domestic terminal is up at the north end of the field, about as far as you can get from our terminal. …… he must have taken a tailwind.” About twenty seconds later he asked the F/O “find out what the wind is.” Approach responded “wind is 010 at 4 knots, do you want runway 17?” The F/O replied “standby.” The Captain then said, “hmmm, if we take 17 we’ll save about eight or nine minutes plus we won’t have to taxi the full length back. We’ve got about fifty miles….. tell him we’ll take 17”. The F/O duly confirmed that XXX99 was requesting a straight-in on Runway 17.

At 2229 the Captain said “have you got the 17 plate?” but the F/O’s response was interrupted by a radio call from Sommeton Approach, who asked XXX99 its DME from STN. The F/O replied “DME 30”. Approach then cleared XXX99 to turn left and join the 17 ILS, cleared to JOYNR at 4000 feet. The Captain then said “OK, we’re a bit high now, so I’ll get it all off so we get in the groove again as soon as we can”, extended full speed-brakes, and turned onto a heading of 120.

F/O: That’s 110.7, “ISS”, I’ve identified the 17 ILS for you.

Capt. Thanks… I guess that’s Ridgeville up ahead. Should hit the ILS soon - I’ll make it 140 (degrees heading).

Shortly afterwards, the Captain retracted the speed-brakes and called for ten flaps.

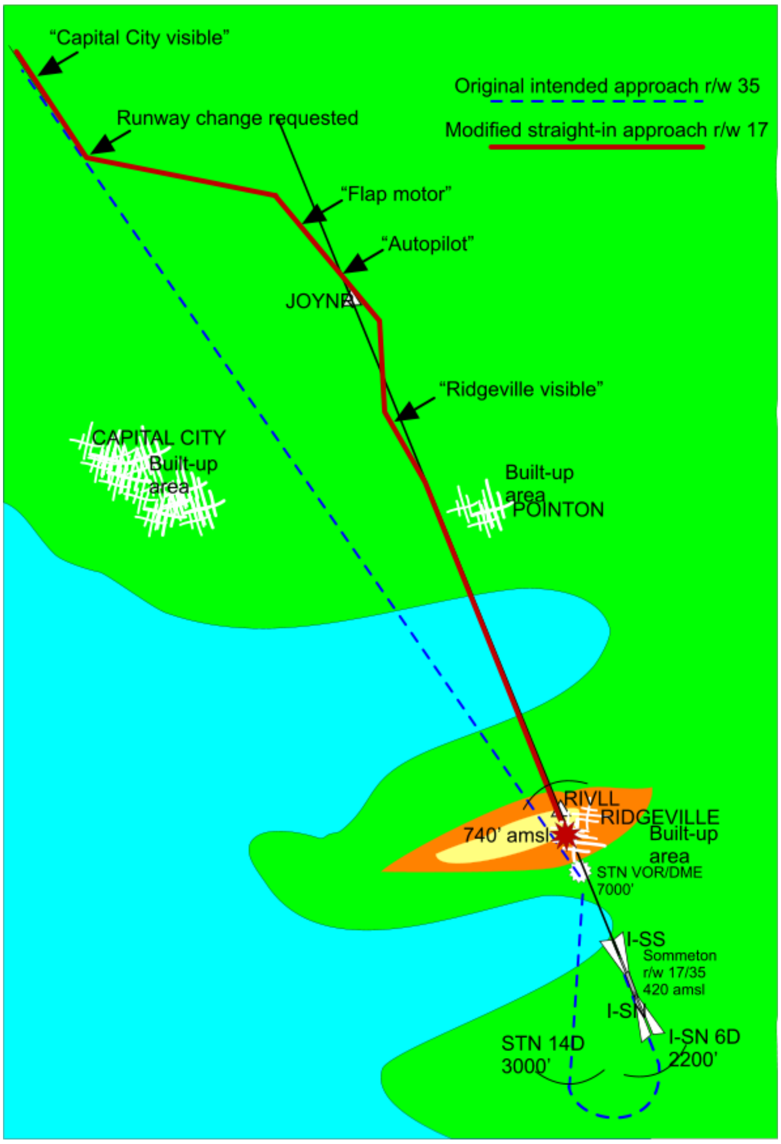
F/O: Speed checked, ten flaps……. By the way you need to go to raw data not map.

Capt. Oh yes. OK. Thanks.

An alert tone sounded.

F/O: Uh oh what’s that….. it’s “Flap Motor”.

Capt: OK I'll hold this speed, you do the "Flap Motor" checklist.
F/O: um….. it says "do not use standby motor….. use 27 flap on selector…. use V_{app} 32 plus 25 kts……check landing distance". Just a minute……"
Capt: OK….
F/O: I make it it's too short - this chart's a bit confusing but I……..
Capt:. No I'm sure it's not too short, have another look…
Capt: S*** it's gone through the localizer. The Autopilot disconnect alert sounded.
Capt: I've taken it out - I can see Ridgeville. Maintaining 4000.
The Captain then made several turns to re-establish on the ILS centerline.
F/O: OK I think you're OK for landing distance - do you want to check it?
Capt: No, we need to get down. Do you have a glideslope your side?
F/O: uh no……. your final speed's gonna be 170.. Are you sure about the... it looks.......



Approach: XXX99 you are cleared for the approach 17 call the tower.
XXX99: Roger
Capt. OK we're on the ILS, select flap 18, I'm reducing to 190… where's that Glideslope? We can go down to 2200 at Ridgeville…. 7 on the DME like we said.. (Speed-brakes then stowed)…. Give me the landing checklist when you can….. are you sure that speed's right, sounds a bit high.
F/O: hang on… oh no it's based on the 32 flap setting not the 27 we were planning on. But you only select to 27.
Capt: yeah its confusing. I still don't have a glide-slope - what height should we be at on that DME?
F/O: uh…. Let's see……. I think it's 2200, we're at 6.
Capt. OK we're in the groove then, ask him where's that glideslope.
Approach confirmed glideslope is off due to power problem, and changed XXX99 to tower.
Capt: call me the DME heights.
Radio altimeter voice was heard at this point: "One thousand"
F/O: this doesn't seem right somehow.
Capt. Did you call the tower? - I can see the ground

F/O: OK, DME 4, should be 1600 - you’re about 80 high.
Tower was contacted and landing clearance obtained, wind 010 at 3 knots.
F/O: landing check is complete, should be 900 feet.
Capt: funny I don’t have the runway
F/O: I don’t think we should….
Capt: something ain’t right - we’ll go around. Go-round, flap 18.

Thrust levers were fully advanced and the aircraft rotated but the aircraft hit a group of houses on the top of a ridge at 740 ft. m.s.l. There were no survivors among the 179 passengers and crew, and 46 casualties on the ground.

In the subsequent investigation it transpired that the DME readings and aircraft altitudes corresponded to an accurately flown profile using the DME distances from the ILS DME shown on the 17 approach plate. Unfortunately however the only DME being displayed was that for STN, some 4 miles out on the centre-line. Consequently the profile was actually flown 1200 feet low, and the aircraft hit the village (Ridgeville) on the ridge north of the bay. Although the aircraft was fitted with GPWS no alerts were triggered, because the aircraft did not penetrate any of the mode boundaries. The town which the Captain thought he had identified as Ridgeville was actually Pointon, situated in a geographically similar location north of an inlet some seven miles further North. The actual weather at Sommeton was visibility 3 km. in haze, cloud 400 ft scattered, 600 broken. Consequently neither Sommeton nor Ridgeville were actually visible at any time from the aircraft.

So what was the original cause of the accident? In retrospect it is easy to see that the Captain became overloaded by having to fly the aircraft and simultaneously manage all other aspects of the flight, particularly after the autopilot failed to cope with the additional speed resulting from the flap abnormality. Consequently his overall situational awareness was impaired. The First Officer’s situational awareness was also impaired by the need to obtain the detailed information on handling the flap abnormality, and then to assist the captain by providing him with specific height information. His situational awareness was better - he was concerned that “something wasn’t right” earlier than the Captain - but he was unable to translate this into effective action. Despite the lack of some facilities - map display, ILS Glideslope and ILS DME - sufficient information to conduct the approach safely remained available, but the crew did not make full use of it.

One conclusion that could be reached is simply that the accident was caused by the failure of the crew to follow their SOPs. For example the SOP required that a detailed briefing be carried out for the approach being used. The Captain briefed for R/W 35, but actually used R/W 17. Most aspects of the briefing would have been identical, but the specific approach plate was not. The Captain’s attempt to address this was interrupted by ATC, and he did not return to it, perhaps because he was confident that his experienced F/O did not need detailed instructions on interpreting it.

The SOPs also advised that “In situations generating high workload, such as serious aircraft deficiencies, Captains should give consideration to delegating the flying to the co-pilot, in order to give maximum attention to the effect of such deficiencies on the safety of the flight”. Clearly in this case the workload became excessive, but the Captain did not follow this advice on effective Crew Resource Management. So what factors went into generating the excessive workload, and the failure to manage resources effectively?

The Captain, although very experienced, was by no means a “domineering” type of person. In his briefing he made it clear that he wanted the F/O to vocalise any concerns.

Subsequently, when the F/O queried the Captain's interpretation of the altitude clearance, he supported obtaining clarification, and thanked the F/O for pointing out the error. Later, he thanked him for prompting over the need to switch from map to raw data. Likewise, the F/O was quite experienced, and had no difficulty in querying the Captain's action regarding the altitude, or prompting him when he detected an omission. The interpersonal CRM attitudes of the crew would be hard to fault.

The flight was running late, and the crew recognised that it would be desirable to retrieve some of the lost time. Although they were fully expecting to be able to depart before the extended curfew, any additional delay would result in a significant problem with an enforced overnight stop and all the subsequent cost and other penalties. Although he had planned for a full instrument approach, however, the Captain's mental model of the situation was biased by the fact that the forecast was for relatively benign weather (10 km.+, cloud 1500' scattered, 4000' broken, temporarily visibility 3500m in haze, 700' broken), and the received ATIS seemed to confirm this. In addition, he could clearly see places many miles away, from cruise altitude. His expectation was obviously that he would be able to transition to visual flight considerably above the Decision Height for the approach. This was further reinforced by the fact that the only weather information that was actually current was passed to him was in response to his query about the wind: the ATIS information did not reflect the actual conditions in the approach area. The Captain was familiar with the airport and its surrounding terrain, but the F/O had never been there before. So the F/O could be expected to regard the Captain's judgement on what was safe in this particular location as being superior to his own, and to want to learn from the Captain in this regard.

Despite these factors reducing the apparent need for a "bad weather" arrival, the Captain did formulate a complete plan for an instrument approach down to a mile from the runway, that would have ensured a safe arrival if followed through.

The first point where the plan was amended was when the crew were advised of the opposite traffic, and realised it had not used the runway stated on the ATIS. This led to the Captain discovering that the wind was not exactly as reported. That in turn led him to realise that he could not only reduce the time pressure due to the late operation, but also make some economic savings for the airline. By making a straight in approach, not only would the flight time be reduced by several minutes, but he could avoid the lengthy taxiing back from the far end of the runway, and turn almost straight onto the terminal ramp after landing. At a range of some 50 miles or more from the airport, a change of runway should be well within the crew and aircraft capability, especially in essentially good weather, but it did require prompt action to adjust the descent profile, which was taken. However, this decision reduced the available time to complete the operation, and increased the crew workload significantly.

The second significant change then came when the crew attempted to extend the flaps whilst turning in to join the 17 ILS. This relatively minor technical defect had two major effects: it increased the F/O's workload significantly as although the checklist items were very limited, they required concentration on the detail of a complex chart, with which he was not very familiar. It also meant that the aircraft's speed had to be maintained considerably higher than was desirable, further compressing the time-scale and increasing the Captain's workload. The Captain's workload then took another step up when, because the speed was high, the autopilot was unable to execute a good capture of the ILS localiser.

The need to hand-fly from this point dramatically reduced the Captain's "spare" capacity. His familiarity with the area meant that the combination of "recognised landmarks" and apparently "good weather" allowed him to be satisfied that it was safe to continue, because he was confident that he would not only have full ILS instrument guidance, but the visual information would also improve rapidly as the aircraft descended. However, because he now had so little spare mental capacity he was unable to consider some of the other facts which had been of relatively little significance earlier, such as the promulgated unreliability of the 17 ILS glideslope, and unserviceability of the 17 ILS DME. The F/O meanwhile had no particular reason to question the Captain's judgement, especially since the Captain had proven right in stating (from experience) that the runway would be long enough for the flap condition, when the F/O had had difficulty in extracting this data under pressure. The F/O saw his main task as assisting the Captain as much as he could and in ensuring that the landing checks were properly completed as commanded.

When it became apparent that the glideslope information was not going to appear it became necessary to find some substitute. Since the ILS plate also contained DME data, it was obvious that this would be the thing to use, particularly since it was after all only needed as a temporary supplement to the visual cues - the Captain thought he knew where he was, and expected to become visual any time after 4000 feet. The only DME data on display confirmed this mental model, and corresponded with the values which had been given in the initial briefing, although they were for the opposite runway and the source changed in that approach from the STN DME to the 35 ILS DME.

Nevertheless, other factors somehow caused the F/O to have doubts, which he vocalised when the Radio altimeter audio came on., but these were not strong enough to convince him that his judgement was better than that of the Captain, who knew the area, could see the ground, and was both flying the aircraft and in command. Very soon after, both pilots became seriously alarmed that things were not working out as they had anticipated - but by then, it was too late.

The Captain failed to recognise that his workload had risen to the point where his situational awareness and judgement was becoming impaired. This was however inevitable, since the reason for this failure was the workload itself. The company SOPs recommended that in such circumstances, he actually should abandon the **basic** SOP, and delegate the flying so as to better retain overall command judgement - but did not tell him how to recognise that situation. The example given in the SOPs implied that high workload would arise in the event of serious aircraft deficiencies, which is true, but not comprehensive. If, with the benefit of hindsight, we query the Captain's judgement, we have in turn to answer this question: *what was the appropriate point for him to have decided that the situation justified departing from the airline's basic SOP, (which required him as Pilot-in-Charge to act as pilot flying), and ask his First Officer to act as pilot flying while he resolved more significant problems - a decision which in itself would signal to the First Officer that a major problem had arisen?* Was it

1. When he himself realised that "something wasn't right" and initiated the go-around - by which time disaster was unavoidable?

2. When the F/O commented that "something wasn't right" at 1000 ft. radio - by which time the aircraft was already well established on the wrong profile?

3. When they established that the glide-slope was not available - but is glide-slope failure a "major problem"?

4. When the autopilot failed to capture the ILS localiser - but is hand-flying so difficult?

5. When the "flap motor" alert occurred - but is that a "major aircraft defect"?

6. When it was decided to switch from runway 35 to 17 - but is changing runways such a big deal?

7. When the aircraft departed 90 minutes off schedule from its previous station - but is just being late so unusual?

It can be seen that in fact each of these events (perhaps as well as others) contributed to the situation, but no single one can be clearly identified as THE point where every pilot would agree it would have been desirable for the Captain to give himself a bit more opportunity to assess the situation. Moreover, at most of these points the workload rose as result of decisions by the crew themselves - requiring a paradoxical recognition that a decision which was believed to be sound had made the flight less safe.

In fact it is only by revising the basic allocation of duties so that delegation is the normal procedure, that the Captain would not have been faced with this problem. If that had been the case then the risk would have been significantly lower.

It would be easy to construct a parallel, fictional tale using the alternative procedure and which (obviously) did not terminate in disaster - but futile, as it would hardly be convincing. Instead, one must just ask whether it is more or less likely that events would have worked out differently. For example, if the First Officer had been asked to conduct the entire descent and approach (on instruments, and without the need to acquire visual cues), and his workload started to increase due to the need to hand-fly the aircraft, is it more or less likely that he would have used the external scene as a substitute for instrument information? If the Captain had been the first one to become concerned that they were not actually in the right place, is it more or less likely that the crew would have initiated an early go-around? If the Captain had been the one to be concerned (rightly or wrongly) that there was no longer enough landing distance, is it more or less likely that the crew would have taken some delaying action (such as a hold) whilst establishing the correct data?

This author's view is that in most cases, any individual's ability to evaluate the overall situation is enhanced by offloading short-term manipulative tasks. However if those tasks have been retained, it becomes increasingly harder to assess one's own workload level. The ability to conform to the advice to "delegate for better CRM in high workload situations", particularly where these may have been even partially self-induced (as in this case, with the decision to change the planned arrival runway) may also be severely constrained by a natural reluctance to admit that a difficult situation has developed. The "strong individual" culture of many pilots gives a powerful psychological incentive to continue acting as though everything is absolutely under control, even when a more objective evaluation would suggest that an individual's limits are being reached.

Equally, all pilot training engrains a need to *stick to SOPs,* especially when things go wrong. A captain who follows the advice given - "in situations generating high workload, such as serious aircraft deficiencies, Captains should give consideration to delegating the flying to the co-pilot, in order to give maximum attention to the effect of such situations on the safety of the flight" is saying, in fact, "we have such a serious problem that we have to deviate from our normal SOPs, because they can't cope with the situation" - and an unspoken subtext to that would be "and we're on our own from here on".

Making such a statement both requires a major intellectual and emotional effort on the part of the Captain, and has a consequent and significant intellectual and emotional effect on the First Officer; indeed, it may induce undesirable additional stress in the latter in particular.

It recognizes in fact that the flight is now outside the normal range of safe operation, so the normal procedures can no longer apply.

For this crew, their basic SOP was not fault-tolerant, because it did not assume that entirely normal imperfections - time pressure, technical problems, incorrect weather reporting and unreliable facilities - would sometimes combine into a predictable high risk situation. When they did coincide, it took relatively little by way of human failure to let the situation to get out of control. **The only way to maximise the probability that all resources will be used when needed is to ensure that this is built into the basic procedures to which all pilots are expected to conform.** This removes the conflict between good CRM for abnormal situations, and normal duty allocations for normal operations.

Appendix 6: a specimen SOP allocation of duties.

This appendix is intended to illustrate (in a very simplified manner) how the principles described can be translated into practical instructions. It is initially assumed that the Captain will act as P1, but at his discretion, P1 and P2 duties may be exchanged, except for actions required by regulation to be carried out by the Pilot in Command which are notified as “Captain” in the P1 column.

For practical purposes the flight is broken into three segments: (1) pre-departure and takeoff; (2) climb, en-route and approach, and (3) landing. The takeoff phase ends when the after takeoff check is completed. The landing phase starts when the P1 has made a decision to land after obtaining the necessary visual references, and ends at the parking gate. This results in a practical minimum number of times control is handed over, while providing the maximum practical level of error detection and correction. The P1 is the handling pilot (HP) for takeoff and landing (including taxying), but delegates the handling for the other flight phases.

Standard call-outs are not specified here: there is no change required to an airline’s current requirements in this respect except to ensure that they assigned to the appropriate pilot as P1 or P2. In addition, whatever callout is made at minimums will also signal the transfer of control if adequate visual reference has been obtained: e.g. if the P2 callout is “Minimums” or “Decide” the P1 response might be “Landing”, signifying that the P1 is taking control, or “Go-around” instructing the P2 to carry out the go-around.

It should be noted that nothing in this suggested allocation of duties would affect an airline's current policies in respect of "role reversal", "leg-and-leg" flying, "First Officers sectors" or other aspects which revolve around exchange of duties. Appendix 4 addresses this issue in more detail.

P1	**P2**	*Comments*
Pre-departure through to end of after-takeoff check:		
Duties as currently assigned to "pilot flying" (PF).	Duties as currently assigned to "pilot not flying" (PNF).	*No change from "assisted" concept. However, assigning handling of actual engine start may be desirable, as period around engine starting is frequently one of very high workload. P1 priority should be command and supervision, dealing with communication, liaison, and strategy.*
CAPTAIN: actions required by regulation to be carried out by the aircraft commander		*Specified as Captain, not as P1. Examples: signatures on specific documents.*
Climb, cruise, descent and approach:		
Command and communication, and duties currently assigned to "pilot not flying" (PNF).	Control aircraft, and any non-command duties as currently assigned to "pilot flying" (PF).	*Maximizes error detection and correction probability. Maximizes CRM capability Maximizes P1 capacity for problem anticipation, detection and solution.*
Review and approve P2 approach plan, and conduct appropriate briefing.	Planning and execution of approach, using appropriate level of automation.	*Incorporates ICAO CFIT recommendation as standard procedure.*
Acquires visual cues and takes control for landing, *or*	Relinquishes control and continues specific duties currently assigned to "pilot not flying" (PNF).	*Incorporates ICAO CFIT recommendation as standard procedure*
Calls for go-around	Executes go-around.	*Eliminates need for flying pilot to attempt to change from instruments to visual and back to instruments for go-around*
Landing and after landing:		
Control aircraft, and duties as currently assigned to "pilot flying" (PF).	Specific duties currently assigned to "pilot not flying" (PNF).	*No change from "assisted" concept.*

About the author.

Steve Last was a professional airline pilot flying international and intercontinental routes for 35 years. At the age of 18 he entered the College of Air Training, a specialist airline flight training establishment set up by the then British state-owned airlines, British European Airways (BEA) and British Overseas Airways (BOAC). In 1965 he joined BEA as a co-pilot on the De Haviland Trident (the first three-engined jet), at the time the most technically sophisticated airliner flying, and on which the first passenger carrying autoland operations were performed, leading to the world's first Category 3B approval. At the age of 30 he was promoted to Captain on the Vickers Vanguard (a large four-engined turboprop), operating scheduled and charter freight services in Europe and the Mediterranean. He then returned to passenger flying in British Airways as a Captain on the Trident, Boeing 757, Airbus A320, and Boeing 747-400, on which he was the most senior Captain on retirement in February 2000.

Steve Last was involved in air safety and standards activity for most of his career. He held positions as Vice-Chairman of the Technical Committee of the British Airline Pilots' Association (BALPA), and within the International Federation of Airline Pilots Associations (IFALPA) where among other positions he was elected as Principal Vice President for Technical Standards, Principal Vice President for Administration and Finance, and Chairman of the Aircraft Design and Operations Committee.

As an IFALPA nominee he was involved with various international organisations, including the International Civil Aviation Organisation (ICAO) (Airworthiness Committee, Operations Panel, and ETOPs Study Group); JAA (Human Factors Steering Group); and Society of Automotive Engineers (G-10 Human Behavioral Engineering Technology). On retirement from BA he continued as the Chairman of the SAE's S-7 (Flight Deck and Handling Qualities for Transport Aircraft) Committee, and is the author of several SAE papers.

In 1989 Steve Last was asked to join the Flight Operations Technical Projects Department of British Airways, as Project Pilot for the Canadair Regional Jet, and was Technical Officer for Developing Technologies until 1996. He has participated in numerous technical trials and evaluations, and acted as adviser and consultant to the UK CAA and to Avionics Vendors.

After retirement he continued as a flight operations technical consultant to a major avionics company and was a frequent request speaker, session leader or chairman at airline industry technical meetings and symposia. He subsequently ceased active involvement after flight operation technical activity, but retains a personal interest in reducing "crew caused" accidents.