Flight Operations Briefing Notes

Human Performance

Error Management

I Introduction

With the achieved high reliability of modern aircraft systems, human performance has become a key focus area for flight safety. Various types of human error are often quoted as contributing factors to incidents and accidents.

Safety officers at airlines observe human errors and even violations when they monitor the safety performance of their airline through safety reports and Flight Data Monitoring.

Information or training alone cannot immunize a person or an organization against error. Improvement is only achieved through concrete improvements that make errors less probable and their consequences less severe.

The objectives of this Flight Operations Briefing Note are:

- To familiarize the reader with the key concepts of human error and violation
- To guide the reader towards productive solutions in error and violation management.

The perspective of this Briefing Note is at the organizational level. In other words, the aim is to help Safety Managers, Training Managers and other similar people to apply the most effective systemic solutions for managing errors and violations in their organization. Even if the Briefing Note certainly gives ideas for Error Management also at the individual level, it is not the primary aim here to give pilots new Threat and Error Management techniques, but rather to try reduce the number and gravity of Threats they face in the operation.

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II Defining Human Error and Violation

II.1 Errors and Violations

In everyday language, the term "error" is used in a very broad sense. For a more detailed discussion of the topic, more precise definitions are needed. The classification used here is in line with James Reason's definitions.

Errors *are intentional (in)actions, which fail to achieve their intended outcomes.*

Errors can only be associated with actions with a clear intention to achieve a specific intended outcome. Therefore, uncontrolled movements, e.g. reflexes are not considered errors. The error itself by definition is not intentional, but the original planned action has to be intentional. Furthermore, it is assumed in the above definition that the outcome is not determined by factors outside the control of the actor.

Violations *are intentional (in)actions, which violate known rules, procedures or norms.*

The fundamental difference between errors and violations is that violations are deliberate, whereas errors are not. In other words, commiting a violation is a conscious decision, whereas errors occur irrespective of one's will to avoid them. Cases of intentional sabotage and theoretical cases of unintentional violation (breaking a rule because the person is not aware of the rule) are outside the scope of this Flight Operations Briefing Note.

Therefore, it is important to realize that within the scope of our discussion a person committing a violation does not intend the dramatic negative consequences which sometimes follow a violation - usually it is belived *bona fide* that the situation remains under control despite the violation.

It is worth noting that many sources, even in the domain of aviation safety, use the term "error" in a wider sense, covering both errors (as defined here) and violations.

Errors can further be divided into the two following categories:

- **Slips and lapses** *are failures in the execution of the intended action.*

  Slips are actions that do not go as planned, while lapses are memory failures. For example, operating the flap lever instead of the (intended) gear lever is a slip. Forgetting a checklist item is a lapse.

- **Mistakes** *are failures in the plan of action. Even if execution of the plan was correct, it would not be possible to achieve the intended outcome.*

  Plans that lead to mistakes can be deficient (not good for anything), inappropriate good plans (good for another situation), clumsy (with side-effects) or dangerous (with increased risks).

Figure 1 summarizes the defined concepts.

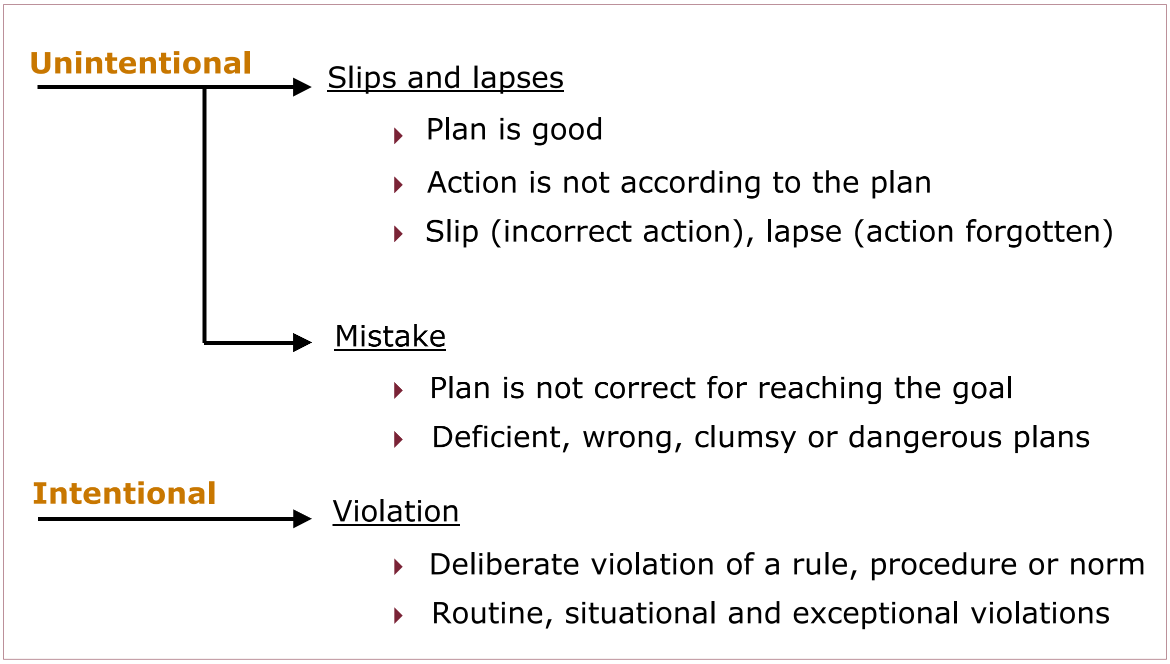

Figure 1

Summary of Errors and Violations

II.2 Performance Levels

Different error types are often associated with so-called performance levels. At any point in time, a person usually performs several tasks simultaneously. For example, a pilot may be flying the aircraft manually (reading instruments, analyzing the situation and giving inputs to flight controls), going through the checklist read by the PNF and remaining vigilant for any radio traffic. In order to be capable of such multi-tasking, despite limited attentional resources, the human cognition is able to perform familiar tasks with minimal attention and the most familiar tasks automatically.

This capability can be modeled with Rasmussen's skill-based, rule-based, knowledge-based presentation of performance levels. Rasmussen's model is briefly introduced below.

Applying learned routine skills in normal well-known situations is skill-based performance.

Example – Skill-based Performance

When flying the aircraft manually, an experienced pilot does not need to focus the attention on the physical routines of moving the sidestick and operating the thrust levers. Such routines have become automatic "programs" that can be run while the pilot allocates the conscious attention on something else – typically on where (s)he wants to fly the aircraft.

In the hierarchy of performance levels, the next level is rule-based performance. In rule-based performance the person is confronted with a situation where attention must be focused on making a decision or creating a solution. However, the situation is a well-known one, for which the person has been trained. Therefore, as soon as the situation has been identified, the person can easily apply a known solution and carry on with the original activity, often returning to the skill-based level. The name "rule-based" reflects the existence of learned solutions providing IF-THEN "rules" that can be applied to the situation – not necessarily rules in the classical sense, i.e. regulations or norms.

Example – Rule-based Performance

The automatic routine of taxiing on an empty straight taxiway may be interrupted by the observation of an animal running in front of the aircraft, requiring momentary attention, diagnosis of the situation and a decision on the action to take. What is the animal? How far is it and where is it going? Is there a risk the aircraft will be damaged? Should the aircraft be slowed down, stopped or can taxiing continue normally?

Training and experience allows a person to construct a collection of rules, to know when to apply these rules and to know which clues to use to identify a situation correctly. For instance, at the time when windshear and microburst phenomena were still not well known within the aviation community, many flight crews found themselves in a surprising situation where it was difficult to understand what was happening, and without any effective solutions to apply. Sometimes the consequences were disastrous. Since these phenomena have been better known, crews have been trained to identify the situation rapidly and correctly, and to apply the correct flying techniques.

The most attention-consuming performance level is the knowledge-based level. In a completely new situation, without the help of any existing solutions, the person is forced to face the painful task of trying to find an on-the-spot solution, based solely on the knowledge of the system. When such a situation emerges in the context of a complex system and under time pressure, the analytical capacity of the human cognition is quickly surpassed, and the chances for a successful outcome are seriously compromized. Preventing crew members from getting into such situations is one of the self-evident guiding principles in aviation.

Example – Knowledge-based Performance

Two cases that involved a total loss of hydraulics, the DC-10 at Sioux City 1989 (uncontained engine failure) and the A300 in Baghdad 2001 (hit by a missile), serve as rare examples where the flight crew were successful in the almost impossible task of learning to fly a damaged aircraft with engine power only, and landing it. In these cases the flight crew could only rely on the on-the-spot reasoning, experimenting and overall knowledge of the aircraft and flying.

Errors and violations have different forms at different performance levels.

Slips and lapses typically emerge at the skill-based level. There are several known mechanisms behind slips and lapses. It is known, for example, that mental "programs" which are most commonly used, may take over from very similar programs, which are less frequent or exceptional.

Example – Lapse at the skill-based level

The captain learns that a structural repair has been performed on his aircraft prior to the flight due to an earlier ground damage, and decides to take a look at it during the walkaround. However, when he later starts the walkaround check, he quickly falls into the normal routine "program" of performing the walkaround, completely forgetting his exceptional intention to check the damage repair. He realizes his lapse only once back in the cockpit.

Violations at the skill-based level are routine violations: violations that have become part of the persons automated routines, like routinely exceeding the speed limit slightly when driving.

Mistakes are results of conscious decision making, so they occur at rule and knowledge-based performance levels. In both cases, the two typical problem areas are:

- Identifying the situation correctly
- Knowing the correct solution ("rule") to apply.

At the knowledge-based level the challenge is to process an overflowing quantity of information and to understand it in such a way as to be able to make correct diagnosis and decisions. In contrast, at the rule-based level the flow of information may be well within the processing limits, but the partially unconscious process of situation diagnosis and the quality of previously learned solutions ("rules") become critical.

Violations at the rule-based level are usually situational: the person performs the corner-cutting he judges necessary or useful to get the job done. Violations at the knowledge-based level are usually so-called exceptional violations, and sometimes quite serious in their nature.

Figure 2 illustrates the three performance levels.

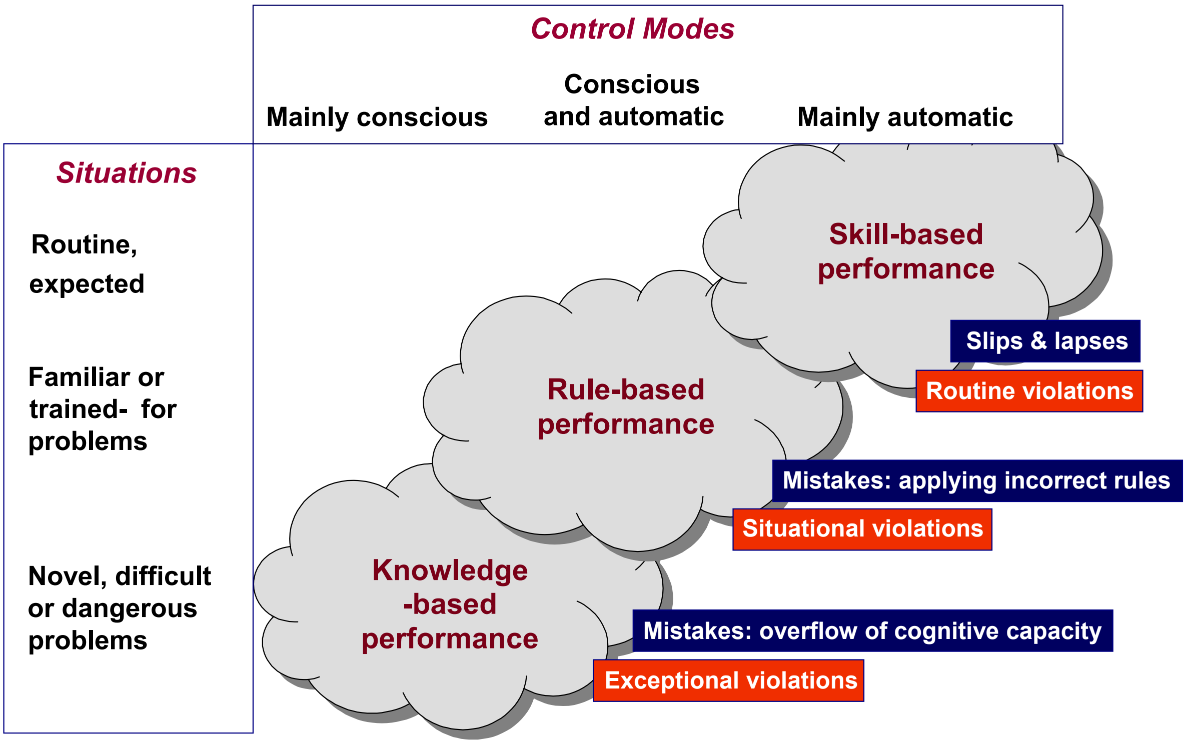

Figure 2

Performance Levels and Main Error and Violation Types
(adapted from Rasmussen and Reason)

II.3 Consequences of Errors and Violations

Errors and violations together form the unreliable part of human performance. It is often stated that 70-90% of current aviation disasters are "due to human factors". While the reality is somewhat more complex, it is true that current accidents usually contain important human performance elements. Errors and violations contribute to accidents both directly and by making the consequences of other problems more serious.

In a complex (at least a priori) high-risk system – like commercial aviation – there are multiple layers of defenses against known types of accidents. Therefore, an accident involves several contributing factors, some usually being quite visible, and others being more distant in time and place from the actual accident. It is important to realize, that in such a system, the consequences of an error depend more on other factors than the apparent gravity of the error itself. In other words, it is wrong to think that a big catastrophe must have been preceded by an equally serious error. It is more the number of errors and the capability of the system to contain the errors, that determine the outcomes.

Examples – Consequences of errors

Error (lapse): Setting the flaps correctly for takeoff is forgotten.

Factors influencing the consequences:

- Aircraft type and performance
- Actual takeoff weight
- Runway length and obstructions ahead
- Functioning of the takeoff configuration warning.

Error (mistake): Navigation error.

Factors influencing the consequences:

- Other aircraft nearby
- High terrain nearby at same or higher altitude as the aircraft
- Functioning of the Traffic Alert and Collision Avoidance System (TCAS)
- Warnings from Air Traffic Control (ATC)
- Functioning of the Enhanced Ground Proximity Warning System (EGPWS).

As these examples portray, the very same error can have completely different consequences, depending on the factors involved.

Some error types tend to have more serious consequences than other:

- Slips are usually easy to detect quickly and do not have immediate serious consequences due to in-built system protections.
- Lapses may be more difficult to detect, and therefore may also be more likely to have consequences.
- Mistakes are even more dangerous, because the person committing the mistake believes that (s)he is doing the correct thing and thus carries on with the action often despite a growing number of signs showing that things are not going right.

- Violations are similar to mistakes but with an increased potential to deviate to an abnormal type of operation – with increased risks. Many violations are tempting because often they bring benefits without any visible drawbacks. The embedded dangers may not be obvious, and people have few chances to learn to appreciate them because violations are forbidden and thus a taboo subject. For example, the violator usually assumes the remainder of the system to be nominal (i.e. no other errors or violations). Ironically, Line Operations Safety Audit (LOSA) data has shown that a violation almost doubles the chances of committing a further error or violation during the remaining flight.

One common false assumption is that errors and violations are limited to incidents and accidents. Recent data from Flight Operations Monitoring (e.g. LOSA) indicate that errors and violations are quite common in flight operations. According to the University of Texas LOSA database, in around 60% of the flights at least one error or violation was observed, the average per flight being 1.5.

A quarter of the errors and violations were mismanaged or had consequences (an undesired aircraft state or an additional error). The study also indicated that a third of the errors were detected and corrected by the flight crew, 4% were detected but made worse, and over 60% of errors remained undetected. This data should underline the fact that errors are normal in flight operations and that, as such, they are usually not immediately dangerous.

Overall, when an error has serious consequences in a highly safety-protected system, it usually tells more about the operational system than about the error itself. Safe systems (like aviation) are supposed to be engineered to manage errors in different ways in order to avoid serious consequences. This is the topic of the next chapter.

III Error Management

People in management positions often find it difficult to deal with human errors. Simple reactions like asking people to be "more careful" very rarely bring any improvement. The seemingly easy solution to add warnings in documentation usually turns out to have a very limited effect. Another natural reaction is to try to train people more, hoping errors would then be avoided. Whereas different technical and non-technical skills can be improved by training, therefore having a positive impact on certain types of mistakes, training does very little in preventing slips and lapses.

Therefore, one must accept the fact that errors cannot be completely prevented no matter how much people are trained and how many warnings are put in the operational documentation.

The first step in successful error management is to understand the nature of the experienced errors and the mechanisms behind them.

Real solutions for human error require systemic improvements in the operation. One way consists of improving working conditions, procedures, and knowledge, in order to reduce the likelihood of error and to improve error detection. Another way is to build more error tolerance into the system, i.e. limit the consequences of errors.

Achieving such systemic solutions requires first adopting an organizational focus to error management, instead of focusing on the individuals committing the errors.

Preventing errors is usually not possible. Therefore the correct term to use is Error Management. This chapter focuses first on the known error management strategies in general, and then goes on to discuss the specifics of managing slips, lapses and mistakes.

III.1 Error Management Strategies

- Error Prevention aims at avoiding the error all-together. This is possible only in some specific cases and, almost without exception, requires design-based solutions.
- Error Reduction aims at minimizing both the likelihood and the magnitude of the error.
- Error Detection aims at making errors apparent as fast and as clearly as possible, and therefore enabling recovery. An error can be:
  - Detected by the person that committed the error (self-monitoring), or
  - Cued by the environment, or
  - Detected by another person.
- Error Recovery aims at making it easy to rapidly recover the system to its safe state after an error has been committed.
- Error Tolerance aims at making the system as tolerant as possible towards error, i.e. minimizing the consequences of errors.

Example – Error prevention

A classic manual engine start routine introduces the potential for engine damage through human error – e.g. by wrong timing of initiation and cutting off the fuel flow. The automatic engine start sequence on FADEC equipped aircraft prevents these errors by precise monitoring of the key engine parameters, correct timing of each step in the sequence and automatic shut-down if anything abnormal occurs during the engine start.

Example – Error reduction

Applying good ergonomics to the cockpit design reduces errors. Shaping the flap, spoiler and landing gear levers to symbolize their functions produces both visual and tactile cues and reduces slips involving the use of the wrong lever. The clear and logical visual design of instruments and displays, like the presentation of speed and altitude on the Primary Flight Display, reduces errors in reading them.

Examples – Error detection

- Performance calculation software can warn the flight crew when some input values are outside the reasonable range, making the error immediately visible (cued by the environment).
- Red-flags on the pins can help detect pins that have been left in position: they can be seen in the wrong place (still at landing gear during taxiing) or their absence in the correct place can alert the crew.
- Crosschecking is a way to apply error detection as an error management strategy (facilitating detection by another person).
- So-called forcing functions are design features, that force a person to detect and correct an error before continuing the task, e.g. the refuel panel of the Hawk-trainer – it cannot be closed if the fuel switch underneath is left in the "ground" position.

Examples – Error recovery

- The undo-function in computer software is perhaps the best-known application of an error recovery feature.
- The possibility to introduce an automatic pull-up function as an extension of the EGPWS has sometimes been discussed. Such a function would introduce forced error recovery.

Example – Error tolerance

Conservative operational margins in performance models ensure that reasonably small errors in aircraft loading and Weight & Balance calculations do not endanger the flight in its critical phases, such as takeoff.

III.2 Managing Slips and Lapses.

Slips and lapses are very much the drawback of the useful human capability to perform actions "automatically", without full attention. The mechanisms causing them function at an unconscious level. Therefore, even if slips and lapses can be reduced through good design of the working interfaces, procedures and environments, it is impossible to prevent all of them.

Examples - Reduction of slips and lapses

- Controlling factors that are known to contribute to errors, like distractions. Among other things, the sterile cockpit principle aims at reducing distractions.
- Standardized procedures reinforce the correct sequences of actions, and thus have a positive impact on both slips and lapses.
- Levers designed with good tactile feedback reduce the risk of slips.
- Use of checklists reduces the risk of lapses.
- An airline was worried about several cases of omitted takeoff flap settings, that were only detected by the takeoff configuration warning. The checklists were changed to include the flap item before the taxi phase, that was considered to be too prone to lapses due to distractions.

The last example also illustrates the already stated fact that effective solutions usually require operational changes at the organizational level.

Due to the somewhat unpredictable nature of slips and lapses, the key management strategies are detection, recovery and tolerance. Fortunately, most slips and lapses are detected, and most often by the actor. As soon as the error is detected, slips and lapses are usually easy to recover.

Examples - Detection, recovery and tolerance of slips and lapses

- To facilitate detection, it is crucial that the aircraft provides the flight crew with immediate good-quality feedback on their actions and that flight crew members are trained to use that feedback systematically to validate that their commands (e.g. autopilot mode changes) are taken into account and implemented correctly.
- The PNF has an important error detection role. In order to truly fulfill the monitoring role, the PNF must know how to monitor the flight effectively in different flight phases.
- The unlocking movements needed to operate flap and spoiler levers may delay the execution of a slipped action in such a way as to facilitate detection either by the actor themselves or by another person.
- Erroneously retracting the flaps at too low a speed or too high an angle of attack causes an Airbus aircraft to activate protections in order to minimize excursions from the desired flight profile. Depending on the situation, slats will remain extended and TOGA thrust may be applied. Thus the error is tolerated.
- Not having retracted the flaps and approaching the speed limit for the configuration will activate the overspeed protections. In this case error detection (overspeed warning) and tolerance (automatic flap retraction) together provide the opportunity for successful error recovery.

III.3 Managing Mistakes

As stated earlier, mistakes are deficient solutions or decisions, often caused by failed situational diagnosis or poor quality of learned solutions.

If a crew found themselves in a knowledge-based problem-solving situation, their chances of success would rely on their basic knowledge of the key phenomena, and the use of skills promoted through CRM training, such as the ability to stay calm, communicate and cooperate. Because mistakes at the knowledge-based level are practically inevitable and difficult to recover, instead of trying to develop related error management strategies, the principle in aviation is simply to prevent crews from getting into such situations. The whole aviation system has been built accordingly.

Scientific data suggests that the probability of correctly recovering from a skill-based slip is double compared to a rule-based mistake, and three times higher than for a knowledge-based mistake. The remainder of this chapter concentrates on rule-based mistakes.

The usable strategies are mistake reduction, detection and recovery. Success in these will be mainly determined by three areas: knowledge, attentional and strategic factors:

- Knowledge is reflected both in how well situations are diagnosed and the quality of the chosen solutions. Adequate knowledge relies on training, experience and availability of updated situational information, like weather and runway conditions.

- Attentional factors determine how easily the relevant information is available. In an ideal case, the attention of the crew is guided to the contextually most relevant and reliable source of information, and the presentation of the information is such that it enables the crew to construct a complete situational understanding rapidly.

  Information overload, distractions and noise should be avoided. When the available information corresponds to attentional resources and informational needs, diagnosis is easier and potential mistakes are more easily detected. Attentional factors are particularly important in view of the biases and heuristics that often distort the diagnostic process.

  Note:

  Heuristics are simple mental rules of thumb which the human mind uses to solve problems and make decision efficiently, especially when facing complex problems or incomplete information. These rules work well under most circumstances, but sometimes lead to systematic misjudgments.

- Strategic factors determine the difficulty of the situation in terms of multiple goals, some of which are often partly in conflict. Usually, some goals are obvious and official, while it is possible that others are hidden, personal or even unconscious goals. Strategic factors become most visible in decision-making situations.

Example – Strategic factors

Following a system failure, the flight crew hesitates between: 1) Landing at the nearest airport that has a short runway and limited landing aids, and, 2) Continuing to the original destination, that is also the airline's base with maintenance facilities and a good runway. Safety, operational and passenger comfort goals all mix together. The flight crew may have their own emotional preference for continuing to the home base, because it also means getting home. There may also be fear of retribution by the company's management, if the flight crew takes the aircraft to an unplanned destination "without real need".

It is clear that while some strategic factors originate from the flight crew, many of them are imposed by the organization and external agents. Obviously, the organization should try to ensure that serious goal conflicts are avoided and that when they arise, safety is not compromised.

A significant proportion of mistakes are caused by incorrect situation diagnosis, which is a particularly problematic task for the human cognition. This is mainly due to the biases and heuristics used by the human cognition in an attempt to process large amounts of information rapidly.

Examples - Biases and heuristics:

- **Expectation bias** helps to fill in the blanks in communications and understand incomplete messages, but can also make the person hear what he expects to hear instead of what was actually said. Expectation bias is hard to counteract. It is important to stress the importance of read-backs and trying to really listen.
- **Availability heuristic** helps to collect information rapidly, but puts more emphasis on the most easily available information sources rather than the most reliable and relevant sources. Availability heuristic can be counteracted through good design of instruments and procedures, and training that teaches the flight crew to focus on the contextually most relevant information sources, and underlines the limitations of the sources.
- **Confirmation bias** helps create a hypothetical diagnosis about the situation rapidly, but the hypothesis is based only on a subset of available information and may lead to fixation, where an incorrect diagnosis is maintained despite an increasing quantity of counter-evidence. This underlines the value of "fresh eyes" making an independent diagnosis.

IV Violation Management

In simple terms, violation management consists of understanding the reasons for violations and then trying to remove these reasons. In an ideal situation, the organization facilitates learning from difficulties in the operations, and fixing them before people need to "fill the gaps" by violating.

There are known factors that increase the probability of committing violations:

- Expectation that rules will have to be bent to get the work done
- Powerfulness: Feeling that skills and experience justify deviating from the standard procedures
- Opportunities for short cuts and other ways of doing things in a seemingly better way
- Poor planning and preparation, putting the person in situations where it is necessary to improvise and solve problems "on the fly" as they arise.

This set of factors is sometimes called "the lethal cocktail".

Often the conditions that induce violations are created, because the organization cannot adapt fast enough to new circumstances. The violator may be a very motivated person, trying to do things "better" for the company. This explains why management pilots are often more likely to violate, especially in small companies where business pressures are strongly felt due to very limited operational flexibility.

Examples - Violations

- The CEO of a small helicopter operator, who was also flying as a Captain, flew scheduled passenger flights without the required co-pilot, sometimes making a non-qualified pilot sit in the co-pilot seat to mask the violation. This exceptional and completely unacceptable behavior probably reflects operational pressures, a high motivation to perform, and a sense of powerfulness.
- Arrival of new aircraft and a growing route network without increasing resources accordingly create a lack of pilots. This, in turn, creates the pressure for some management pilots to "push the duty time limits".
- Over-motivation to bring the aircraft to the scheduled destination, combined with high regard of one's own flying skills, may encourage a pilot to try to "push through the minima" and land.

As with errors, it is important to look for the root causes of violations in the organization. Therefore, the solutions must also be implemented at that level. This also explains why violations are not necessarily always punishable.

It is in no way the intention to undermine the importance of individual responsibility for one's own actions. Dangerous and reckless behavior should never be tolerated. However, some routine or situational violations may have been imposed on the individual by deficient organization or planning, and any individual put in the same situation might find it difficult not to violate.

Acceptance of a non-compliant way of doing the job may have become part of the local working culture, which also means that the whole group – including management - is responsible for the violation, not only the individual actually carrying it out.

The ultimate goal is to establish a working culture, where violations are not an acceptable option. Like all cultural issues, this can take considerable time and effort. Chances for success are greatly enhanced if the employees themselves are involved in setting the limits of what is acceptable in their own work. The limits must then be clearly communicated and imposed.

On a continuous basis, violation management can take four different forms:

- Establish channels for people to communicate difficulties and to discuss solutions. This facilitates learning about problems and adjusting planning accordingly to avoid strains, which could lead to violations.

- Analyze existing violations and assess current violation potential. Try to understand the background of current violations. Use the above list of violation inducing factors to assess potential for future violations.

- Try to ensure that management reduces violations through good leadership and planning.

- Ensure that both management and employees are aware of their responsibilities and key risks related to their work and understand how violations reduce vital safety margins.

V Summary of Key Points

- Errors and violations are more common in flight operations than one would expect. They have the potential to affect safety, although usually the robustness of the aviation system is high enough to contain errors and violations without significant consequences.
- The first step in error and violation management is to understand the mechanics behind them. This Flight Operations Briefing Note has aimed at providing the basic information on the subject.
- Successful management of errors and violations requires continuous application of systemic improvements at the organizational level. Ultimately, violation-free operations should become a natural part of the corporate culture.

VI Associated Flight Operations Briefing Notes

The following Flight Operations Briefing Notes handle topics related to this Briefing Note:

- **Conducting Effective Briefings**
- **Threat Management**
- **Managing Interruptions and Distractions**
- **Effective Pilot/Controller Communications**
- **CRM Aspects in Incidents and Accidents**
- **HF Aspects in Incidents and Accidents**

VII Additional Reading Materials

- James Reason (1990) Human Error, Cambridge University Press, Cambridge, UK
- David D. Woods et al (1994) Behind Human Error: Cognitive Systems, Computers, and Hindsight, CSERIAC State-of-the-Art Report, Wright-Patterson Air Force Base, Ohio, US
- Patrick Hudson, University of Leiden (2000) Non-Adherence to Procedures: Distinguishing Errors and Violations, presentation given to the 11th Airbus Human Factors Symposium, Melbourne, Australia (available at **www.airbusworld.com** / Secure Area / Flight Operations Community / Products and Services / Conferences).

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