8.2.5 Investigating Human Factors

8.2.5.1 General

8.2.5.1.1 This portion of the manual is intended as a general guide to the investigation of the human contribution to aviation occurrences, which advocates a systems approach to the investigation. Whether the investigation is conducted by a single investigator or a team of investigators, the use of a systematic approach will ensure that the investigation of human factors is integrated within the investigation proper and not relegated to the rank of a residual capacity activity, something that happens only if one is allotted enough time and sufficient resources. For both the single investigator and the investigation team, the use of such an approach will make the occurrence investigation more efficient and more complete.

Objective

8.2.5.1.2 The objective of the investigation of human factors in occurrences is to advance aviation safety by:

a) determining how breakdowns in human performance may have caused or contributed to the occurrence;
b) identifying safety hazards as they relate to limitations in human performance; and
c) making recommendations designed to eliminate or reduce the consequences of faulty actions or decisions made by any individual or groups involved in the occurrence.

Scope

8.2.5.1.3 To achieve such an objective, the collection and analysis of human factors information should be as methodical and complete as any other traditional area of the investigation, a requirement that forces the investigation beyond the examination of the actions of the aircrew to include an analysis of any individual or group involved in the occurrence, be it management, the regulator, or the manufacturer.

8.2.5.1.4 In a complex, interactive and well-guarded transportation system such as the aviation industry, accidents rarely originate from actions or non-actions of the front-line operators alone; accidents result from the interaction of a series of latent factors already in the system. In almost every facet of an investigation, from management and supervisory decisions to maintenance activities and pilot performance, one can identify human performance factors that may help to explain the causal event sequence. An investigation that focuses on only the front line operators acts as a barrier to the identification of systemic safety hazards and the opportunity to eliminate or reduce the consequence of safety hazards through the making of recommendations.

Overview

It provides guidelines on the integration of the human factors investigation with the overall investigation. The guidelines are equally applicable to the investigation by a single investigator responsible for all aspects of the investigation, as they are to the investigation where one or more investigators are dedicated solely to the human factors aspects of the investigation.

8.2.5.2 A Systems Approach to the Investigation of Human Factors

Human factors frameworks

8.2.5.2.1 In general, the human factors data that must be collected fall into two broad areas: information which will enable investigators to construct a detailed chronology of each significant event known to have occurred prior to and, if appropriate, following the occurrence (this chronology must place particular emphasis on the behavioral events, and what effect they may have had on the accident events sequence); and contextual information which will permit investigators to explain why the behaviour actually happened.

8.2.5.2.2 The human element can become involved in occurrences in three ways. The first way is as a direct contributor through an unsafe act. Generally, this tends to be an active failure by an operator at the scene of the occurrence and is often referred to as “operator, user or pilot error”. The second way, which also results in direct involvement, is as a receiver/user of unsafe conditions. The third way is an indirect contributor to either unsafe acts or conditions through an antecedent unsafe act or latent failure. This final manner of involvement emphasizes the interrelationships or linkages between unsafe acts and conditions and, therefore, underscores the need to consider various layers of underlying causes and contributing factors.

8.2.5.2.3 Following is a description of four frameworks - the SHEL model, Reason’s Model of Accident Causation, a Latent Unsafe Conditions Framework (LUC), and a Behaviour and Error Framework that will aid the investigator in gathering and analyzing relevant occurrence information to determine the various layers of underlying causes and contributing factors. Subsequent to the description of the four frameworks is a description of an investigative tool, the Integrated Process for Investigating Human Factors, which integrates the four frameworks into an investigative step-by-step process.

SHEL

8.2.5.2.4 The SHEL model (Figure 8-13), originally developed by Edwards (1972) and modified by Hawkins (1987), facilitates a systematic approach to data collection. Each component of the SHEL model (software, hardware, environment, and liveware) represents one of the building blocks of human factors studies.

8.2.5.2.5 The liveware, or the human element, is the centerpiece of the model, representing the most critical and flexible component. The person represented by this component could be any person involved with the operation of a flight, and thus the component should not be considered restricted to aircrew. Each person within this central component brings his or her own limitations and strengths, be they physical, physiological, psychological, or psychosocial.

8.2.5.2.6 The central human component does not act on its own; it interacts directly with each of the others. The edges of this human block are not simple and straight, so other blocks must be carefully matched to them if stress and eventual breakdown (an accident) are to be avoided. The investigation of human factors must identify where mismatches between components existed and contributed to the occurrence, and so the data collected during the investigation should permit a thorough examination and analysis of each of the SHEL components and its interactions with the central component.

a) *Liveware-Hardware (Human-Machine).* This interaction includes any physical or mental interactionsbetween the human and the machine, design limitations and peculiarities in work-station configuration.

b) *Liveware-Software (Human-System).* This interaction concerns the nature of the information transfer between the human and supporting systems such as checklists, manuals, training, procedures, and regulations.

c) *Liveware-Environment (Human-Environment).* This interaction subdivides into two areas:

i) Internal: personal comfort and physical working conditions.

II) External: weather, aerodrome surroundings and infrastructure.

d) Liveware-Liveware (Between People). This interaction explores the nature of human interactions and communication breakdowns between individuals.

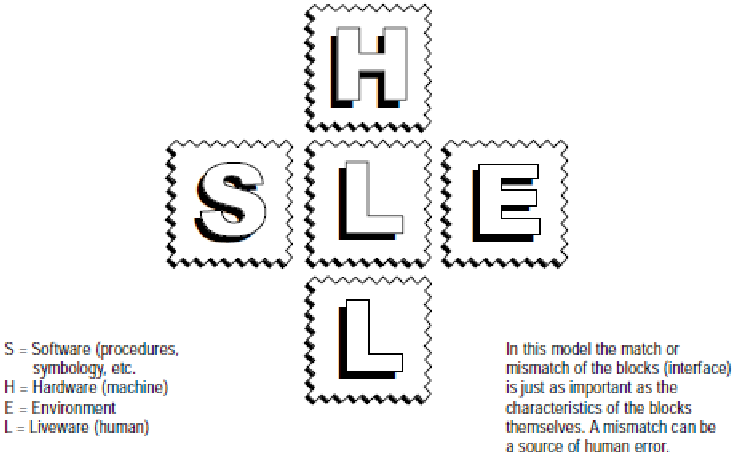

Figure 8-Error! No text of specified style in document.**-1: SHEL Model (Adapted from Hawkins, 1975)**

Reason's model of accident causation

8.2.5.2.7 A framework proposed by James Reason (1990) explains how humans contribute to the breakdown of complex, interactive, and well-guarded systems such as the aviation industry. In such a system, accidents rarely originate from active failures or unsafe acts of front-line operators alone. According to Reason, accidents result from the interaction of a series of flaws, or latent failures, already present in the system (Figure 8-14).

8.2.5.2.8 The two types of failures, active and latent depend upon the immediacy of their consequences. An active failure is an error or violation which has an immediate adverse effect. Active errors are usually made by the front-line operator. A pilot raising the landing gear lever instead of the flap lever exemplifies this failure type. A latent failure is a result of a decision or an action made well before an accident, the negative consequences of which may lie dormant for a long time. These failures usually originate at the decision-maker, regulator, or line management level, that is, people far removed in time and space from the event. A decision to merge two companies without providing training to standardize operating procedures illustrates the latent failure. These failures can also be introduced at any level of the system by the human condition — such as policies that lead to poor motivation or fatigue.

8.2.5.2.9 Latent failures, which originate from questionable decisions or incorrect actions, although not harmful if they occur in isolation, can interact to create a "window of opportunity" for a pilot, an air traffic controller, or mechanic to commit an active failure which breaches all the defenses of the system and results in an accident. The front-line operators are the inheritors of a system's defects. They are the ones dealing with a situation in which technical problems, adverse conditions, or their own actions will reveal the latent failures present in a system. In a well-guarded system, latent and active failures will interact, but they will not often breach the defenses. When the defenses work, the result is a minor event or at most an incident; when they do not, it is an accident.

a) *Upper management decisions.* Amongst these latent failures are decisions made by upper management, an aviation company's corporate managers or regulatory officials. When allocating resources, management has to balance, among other things, safety against cost. These objectives can conflict and may result in flawed decisions which will be reflected throughout the system.
b) *Line management deficiencies.* Managerial decisions, including those that are flawed, have to be implemented by line management through their standard operating procedures, training programmes, flight and crew scheduling, etc. If deficiencies also exist at this level, they will increase the accident potential of those managerial decisions; for example, dispatch who has inadequate appreciation for operational conditions may jeopardize safety by trying to follow a policy which is not appropriate for the situation.
c) *Existing preconditions.* If certain characteristics or preconditions, such as an unproductive environment, poorly motivated or unhealthy workforce, machines in a poor working state, and poorly established procedures are present in the system, they will influence the front line operation's actions and become a source of unsafe acts.
d) *Latent failures.* Flawed decisions at the managerial levels, line management deficiencies, and existing preconditions at the worker level represent the system's latent failures.
e) *Unsafe acts.* Unsafe acts take many forms and, because of error, can never be totally eliminated.
f) *Defenses.* In a complex and well-guarded system, these latent failures may lie dormant for a long time without having significant impact on safety because very effective defenses, such as checks, procedures or GPWS, allow for a great number of these flaws to be simultaneously present in the system without serious consequences.
g) *Window of opportunity.* An accident trajectory occurs when unsafe acts interact with latent failures present in the system and breach all the system defenses, thus creating a "Window of opportunity" for an accident to occur.
h) *Summary.* Many unsafe acts are committed without consequence because existing conditions did not favour an interaction of all the deficiencies present in the system. Investigators, therefore, should not only examine unsafe acts made by front-line operators, but should work their way from unsafe acts and inadequate or removed defenses, through the accident trajectory, all the way back to upper management levels. Addressing the higher levels' deficiencies, in addition to the ones closely related to the unsafe acts, allows the investigator to formulate preventive measures which will affect a larger set of occurrences.

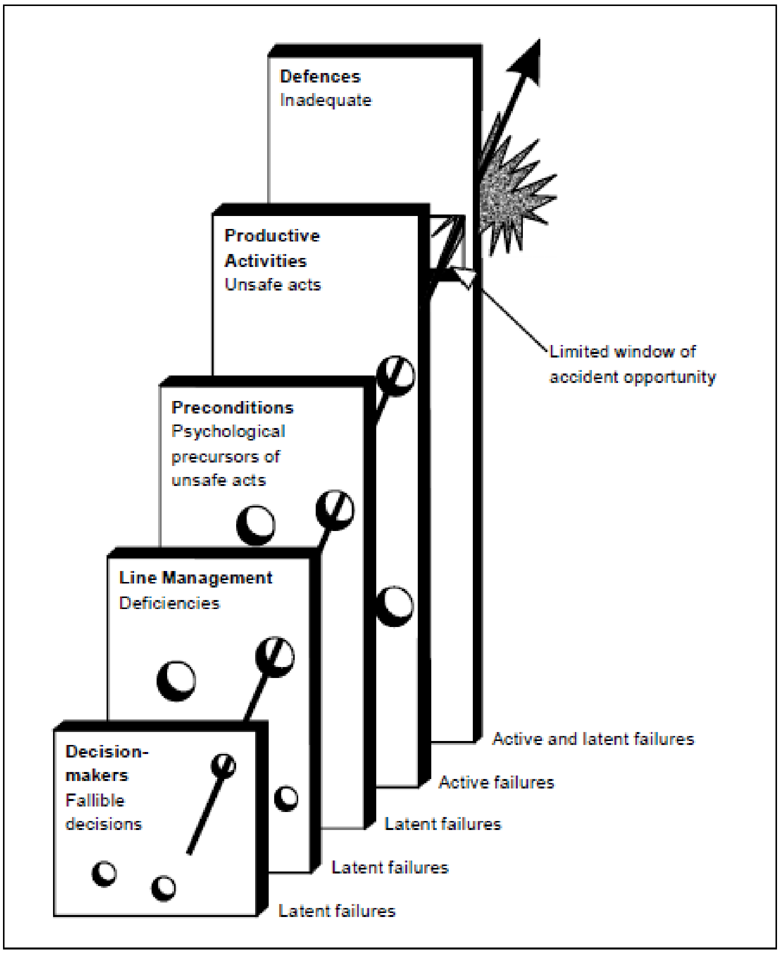

Figure 8-Error! No text of specified style in document.**-2: Reason's Model**

Latent Unsafe Conditions (LUC) framework

8.2.5.2.10 The LUC framework is an extension of the Reason model, with an emphasis on a systematic means for examining personal and organizational factors. This framework comprises the elements of the SHEL model within the Reason concept of latency. Latent unsafe conditions include all those latent factors in the transportation system which can adversely affect safe operations or maintenance. They include latent factors at both the personal and the organizational level and may be referred to as LUC factors. It should be noted that an element of chance is involved in occurrences in the sense that operations may be conducted year after year under the same unsafe conditions without consequence; however, on any given day, an additional element of "bad luck" is added to the equation and tragedy results. Hence, the abbreviation LUC is a reminder of this element of chance.

8.2.5.2.11 Personal latent unsafe conditions (P-LUC factors) include those factors such as the state of mind of the individual, physical wellbeing, etc.; such factors can adversely affect the safety of operations or maintenance activities. Similarly there are organizational latent unsafe conditions (O-

LUC factors); i.e. those factors beyond the purview of the individual which have the potential for adversely affecting personal or team performance in operations or maintenance.

Personal LUC factors

8.2.5.2.12 Latent unsafe conditions at the personal level are known as P-LUC factors. These factors may limit or degrade an individual's expected performance, resulting in an error of some type. The potentially adverse effects of P-LUC factors may be amenable to mitigation by the individual or by the organization, if they are identified in time. Aside from collecting the facts at the individual level, it may be difficult for the transportation system to address "personal" problems. However, sometimes a P-LUC factor will be indicative of a more systemic Organizational LUC factor, which is conducive to broad remediation. P-LUC and O-LUC factors are illustrated within the Reason framework in Figure 8-15 below.

8.2.5.2.13 The P-LUC factors are sometimes referred to as the physical, physiological, psychological, and psychosocial factors.

Organizational LUC factors

8.2.5.2.14 Latent unsafe conditions at the organizational and management level are known as O-LUC factors. Company management practices, the regulatory climate, and even the attitudes of workers fostered by professional associations can adversely affect human performance in both operations and maintenance. Following are some of the principal O-LUC factors:

a) Design:

1) Poor technical design of equipment, including inadequate consideration of the human/machine interface requirements for avoiding human error.

2) Poor task design, failing to take into account all the SHEL model interfaces.

b) Personnel:

1) Inadequacies in the initial (and ongoing) selection of personnel with the requisite knowledge, skills and attitudes for safe and efficient job performance.

2) Deficiencies in the knowledge and skills of employees which are necessary for them to do their jobs safely, resulting from training inadequacies.

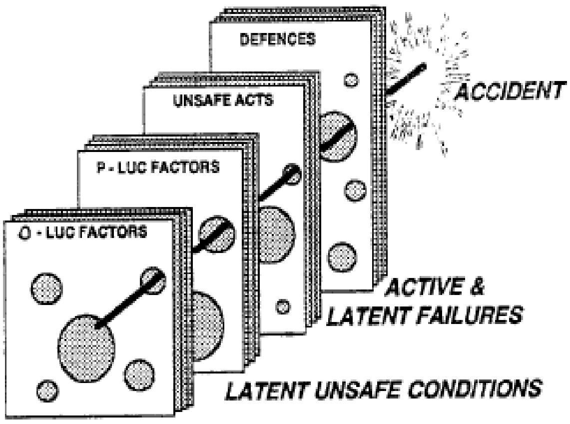

Figure 8-Error! No text of specified style in document.**-3: Latent Unsafe conditions within the Reason framework**

3) Scheduling practices for operating or maintenance personnel which may compromise individual or team performance.

4) Inadequacies in personnel monitoring and support programmes to ensure the continuing fitness of employees for their specified duties.

5) Remuneration practices which provide employees with incentives to cut corners.

c) Procedures and accepted operating practices:

1) Company-prescribed procedures which are difficult to follow, ambiguous, incomplete, incorrect, inaccessible or absent.

2) Accepted operating or maintenance practices which differ from prescribed procedures and create conditions that might lead to errors.

d) Communications:

1) Information necessary for safe and effective operations and maintenance is not sent, received or understood by the intended recipients in a clear, unambiguous and intelligible form.

e) Organization:

1) Deficiencies in the operating philosophy and policies of the organization which create error conducive conditions.

2) Incompatible organizational goals in that production goals are in conflict with the maintenance of a safe operating environment.

3) Deficiencies in either the structure of the organization or its way of conducting business which inhibit effective internal communications between management and operations or maintenance.

4) Deficiencies in the organization's safety climate which allow safety responsibilities to be ill-defined and warning signs to be overlooked.

f) Work environment:

1) Conditions conducive to committing unsafe acts or making safety related errors due to physical conditions in the workplace which influence individual or team performance.

g) Regulatory overview:

1) Deficiencies in the rules and regulations governing transportation operations and maintenance.

2) Deficiencies in the certification of equipment, personnel and/or procedures.

3) Deficiencies in the surveillance, audit and inspection of transportation operations and maintenance.

h) Associations and unions:

1) Philosophies, policies, or practices which create conditions conducive to human error and unsafe acts.

i) Defenses:

1) Deficiencies in the identification and dissemination of known risks and how to manage them; i.e. safety awareness.

2) Deficiencies in providing personnel with adequate detection and warning systems to see an unsafe event unfolding in time to prevent it.

3) Deficiencies in the system's 'error tolerance' such that recovery from an unsafe condition is difficult without sustaining injury or damage.

4) Deficiencies in the emergency response capabilities of the system which aggravate the consequences of an accident.

8.2.5.2.15 These Latent Unsafe Conditions in organization and management provide the operational context for human errors by operators and maintainers. Each LUC factor represents a potential hazard which can be systematically identified, validated, and corrected.

Behaviour and error framework

8.2.5.2.16 The following is a description of modes of behaviour, human error, and the interaction between behaviour and error. The behaviour/error framework has been adapted primarily from Rasmussen's (1987) taxonomy of behaviours and Reason's (1990) generic error-modeling system (GEMS) framework which facilitates the linkage of an error to an individual's level of performance (i.e. behaviour) at the time the failure occurred.

Modes of behaviour

8.2.5.2.17 To understand the ways in which people err, it is necessary to first look at the ways in which they behave. Rasmussen (1987) has identified a taxonomy of behaviours which provides a description of performance based on three different levels of decision-making. The following are descriptions of these three performance levels.

a) *Skill-based performance* describes behaviour for a person engaged in a well-learned activity. Actions tend to be based on stored routines; skill-based performance is largely an automatic response where there is little, if any, conscious decision-making;

b) *Rule-based performance* is less automatic. Decisions are based on learned procedures; these procedures are stored in long-term memory and require the involvement of the central decision maker and working memory because rule-based behaviours are actioned at the conscious level. Response is governed by an "if-then" algorithm, such as "if' this is the situation, then this is the diagnosis; if this is the diagnosis, then this is the remedial action"; and,

c) *Knowledge-based performance* is behaviour that arises when an operator is faced with novel situations for which there are few pre-established rules, but which require that appropriate action be taken. Without rules to guide, decisions are based on the operator's knowledge and experience. Having categorized behaviour using the skill-rule-knowledge-based taxonomy, one can examine how people fail while operating within the behavioural modes.

Human error

8.2.5.2.18 There are two distinct categories of error, those actions that deviate from intention or are unintended (i.e. actions that do not proceed as planned) and those that are intended (i.e. actions that proceed as planned, but they fail to achieve the desired consequences). Errors can be further broken down into types, and the type depends largely on examining the concept of intended action. It is important to note that the criteria of "intentionality" refers to the action itself and not the intention to err.

a) *Unintended actions.* "Was the action that was carried out, the action that was planned?" If the answer to that question is no, then an unintentional action occurred. An unintentional action resulting in an error arises from a failure in the execution of the action in that there was a difference between what action was supposed to have occurred and what action actually did. An error in execution is either a slip or a lapse.

Slips usually arise as the result of not paying sufficient attention to the execution of the action. For example, an operator reaches for a switch, without looking, and places the control in the "OFF" position from the "STANDBY" position, when the intent was to place the switch control in the "ON" position.

A lapse is an unintentional action where there is a memory failure. For example, a person following a series of instructions may forget one of the steps involved in a task.

Whether the error is a slip or a lapse, the planned action is the correct action for the situation; however, the operator fails to execute the action properly.

b) *Intended actions.* "Was the action that was carried out, the action that was planned?" If the answer to that question is yes, then it is an intended action. An intentional action resulting in an error or violation involves a failure in planning in that the intended action was inappropriate. An error in planning is either a mistake or a violation. With this error type, the action proceeds exactly as planned but fails to achieve the desired consequences; in other words, the error is in the planning — it is the incorrect action for the situation. Mistakes are often failures of thought and of the decision-making process.

They are usually more subtle than slips and lapses and considerable time can pass between the execution of the erroneous action and its detection.

Mistakes, where there is no desire to do the wrong thing, can be distinguished from a violation where a deliberate decision to act against a rule or plan has been made. The term violation denotes a calculated adjustment or modification of a rule or plan which differentiates it from the basic error types as defined by the slip, lapse and mistake.

8.2.5.2.19 Despite the deliberate actions, some violations (i.e. routine and exceptional violations) involve people trying to "do the right thing" and differ from sabotage where there is malicious purpose. Routine violations occur every day as people regularly modify or do not strictly comply with work procedures, often because of poorly designed or defined work practices. In contrast, an exceptional violation tends to be a one-time breach of a work practice, such as at Chernobyl where safety regulations were deliberately ignored in order to carry out a safety test. However, the goal was not to commit a malicious act, but actually to improve system safety.

Behaviour/error framework

8.2.5.2.20 Reason's GEMS (1990) provides a framework that combines Rasmussen's skill-rule-knowledge-based behaviour taxonomy with the basic human error types, the result of which yields the following:

1) skill-based slips and lapses;
2) rule-based mistakes; and
3) knowledge-based mistakes.

An argument has been forwarded that violations are typically rule-based and only sometimes knowledge-based (Glendon and McKenna, 1995). However since an assessment or evaluation of information (e.g. a rule or plan) is associated with a violation, this type of failure would appear to occur most often at the knowledge-based level of performance (Hudson, 1991).

a) *Skill-based slips and lapses.* If the error involves skill-based performance, then a slip or a lapse would have occurred due to either inattention or over attention. Inattention is the failure to make a necessary attentional check on progress; over attention involves making the attentional check, but at an inappropriate time in the action sequence. Inattention may result from something as simple as an interruption; in that case, the operator omits the required check because he or she is interrupted or distracted by some external event, such as a radio call interrupting a checklist procedure, resulting in the operator's missing one of the checks. Over attention may also result in an omission. Should the operator believe that the action sequence is further along than it actually is, a necessary step in the sequence can be omitted.

b) *Rule-based mistakes.* If the error involves rule-based performance, then a mistake occurred because either a bad rule was applied or a good rule was misapplied. A bad rule is one that is either incorrect, ineffective or inadvisable (refer to Appendix 1 to Chapter 16 for further discussion of failure modes at the rule-based level). A good rule is one that has proven to be useful under given circumstances. An error involving a misapplication of a good rule is one where the

applied rule is no longer appropriate for the particular circumstances. (See ICAO Doc 9756 Part III
Appendix 1 to Chapter 16 for examples of failure modes at the rule-based level.)

c) *Knowledge-based mistakes.* When no rules apply to a given situation, new solutions or plans must be formulated (Hudson, 1991). An error that is a mistake, that occurs during the formulation of the solutions or plans falls within knowledge-based performance. These errors occur because the operator is without all the information required to form an accurate mental model of the problem space. Failure modes at this level can arise from biases such as confirmation bias where the operator seeks information that will confirm what he or she already believes to be true and discounts information that is inconsistent with the chosen hypothesis. (See ICAO Doc 9756 Part III Appendix 1 to Chapter 16 for examples of failure modes at the knowledge-based level.)

An Integrated Process for Investigating Human Factors

8.2.5.2.21 The work systems/organization and human error/behaviour frameworks, described in 8.2.5.2.1 to 8.2.5.2.20 provide investigators with a focus on the potential unsafe conditions that an investigation of human factors strives to uncover. The following is a process that integrates those frameworks into a step-by-step systematic approach for use in the investigation of human factors. Refer to Appendix 2 to Chapter 16 for greater detail of each step in the process.

8.2.5.2.22 The process can be applied to both types of occurrences, i.e. accidents and incidents. Illustrated in Figure 8-16, the process consists of seven steps:

1) collect occurrence data;
2) determine occurrence sequence; and
3) identify unsafe acts (decisions) and unsafe conditions1;

and then for each unsafe act (decision),

4) identify the error type or adaptation;
5) identify the failure mode;
6) identify behavioural antecedents; and,
7) identify potential safety problems.

Steps 3 to 6 are useful to the investigation because they facilitate the identification of latent unsafe conditions. Step 7, the identification of potential safety problems is based extensively on what factors were identified as behavioural antecedents.

1. At times, an unsafe condition may be a result of a natural occurrence. At other times, an unsafe act or decision may result from an unsafe condition which itself was established by a fallible decision. In the former case, the investigator may jump from Step 3 to Step 7; in the latter case, the investigator should proceed through Steps 3 to 7.

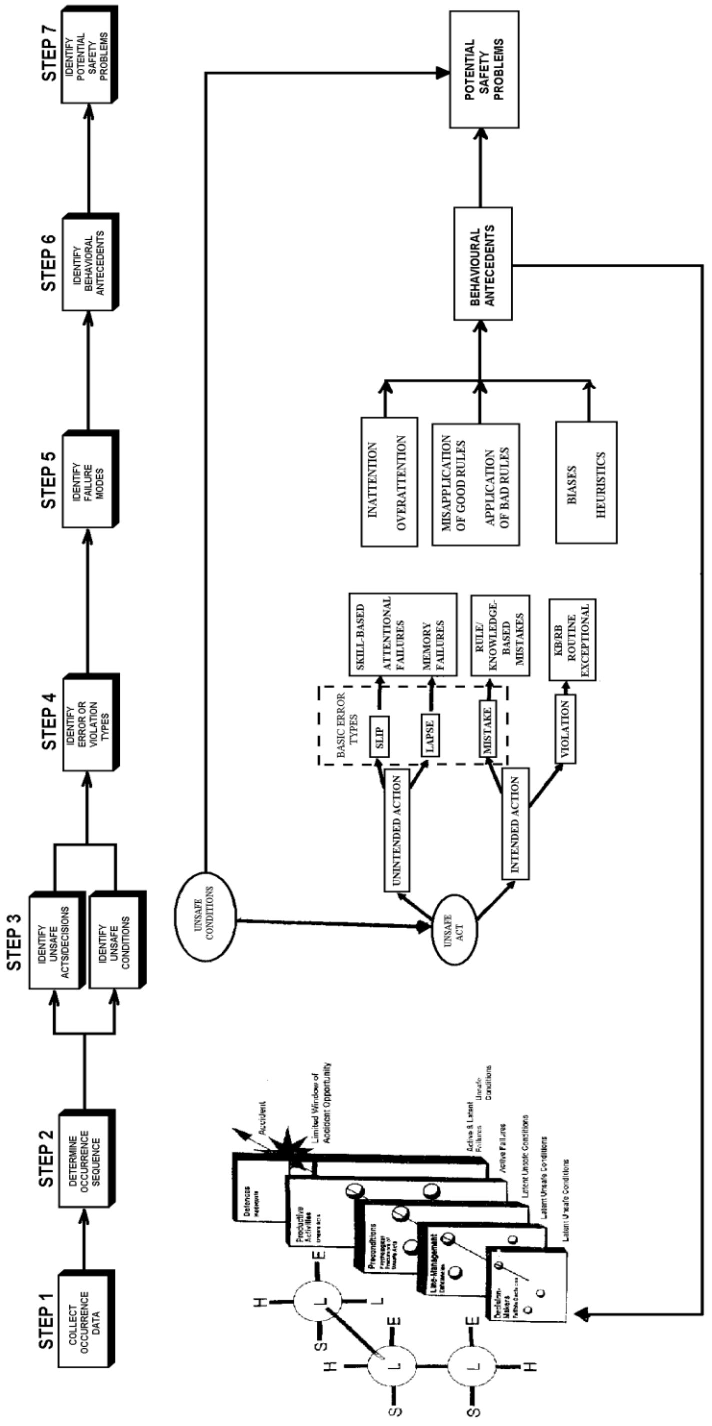

Figure 8-Error! No text of specified style in document.**-4: Integrated process for occurrence investigation**

Step 1 - Collect occurrence data

The first step in the human factors investigation process is the collection of work-related information regarding the personnel, tasks, equipment, and environmental conditions involved in the occurrence.

For complex systems, where there are numerous interactions between the component elements, there is constant danger that critical information will be overlooked or lost during an investigation. Use of the SHEL model as an organizational tool for the investigator's workplace data collections helps avoid problems downstream because:

a) it takes into consideration all the important work system elements;
b) it promotes the consideration of the interrelationships between the work system elements; and
c) it focuses on the factors that influence human performance by relating all peripheral elements to the central liveware element.

Figure 8-17 below is an adapted illustration of how this model can be applied to a complex system where multiple liveware, hardware, software and environmental elements exist.

Step 2 - Determine occurrence sequence

As the investigator moves to addressing questions of "how and why", there is a need to link the events and circumstances identified in the first step of the process. Reason's (1990) model of accident causation, utilizing a production framework, can be used by an investigator as a guide to developing an occurrence sequence. As well, Reason's model facilitates further organization of the work system data collected using the SHEL model, and an improved understanding of their influence on human performance. The occurrence sequence is developed by arranging the information regarding occurrence events and circumstances around one of five production elements, i.e. decision makers, line management, preconditions, productive activities, and defenses.

These production elements themselves are basically aligned in a temporal context. This temporal aspect is an important organizing factor since the events and circumstances that can lead to an accident or incident (and would therefore be causal factors) are not necessarily proximate in time, nor in location, to the site of the occurrence. By establishing a sequential ordering of the causal data, Reason's (1990) concept of active versus latent factors is introduced (refer to 8.2.5.2. 7 to 8.2.5.2.9).

In practice, Steps 1 and 2 may not be mutually exclusive. To facilitate this concurrent activity, the SHEL and Reason models can be combined as illustrated in Figure 8-18.

Step 3 - Unsafe acts/decisions and conditions

In Step 3 of the process, the investigation and/or analysis is simplified where the information gathered and organized using the SHEL, Reason, and LUC frameworks is used to initiate identification of unsafe acts/decisions and conditions.

There may be several acts, decisions and/or conditions which are potential unsafe candidates, thus necessitating iterative assessments of the occurrence facts. The SHEL and Reason hybrid model (refer to Figure 8-18 can provide a useful base for conducting such iterative assessments.
When an unsafe act, decision or condition is identified, the focus shifts to determining the genesis of that particular act.

Further investigation and/or analysis may reveal other unsafe acts/decisions or conditions antecedent to the causal factor that was initially identified.

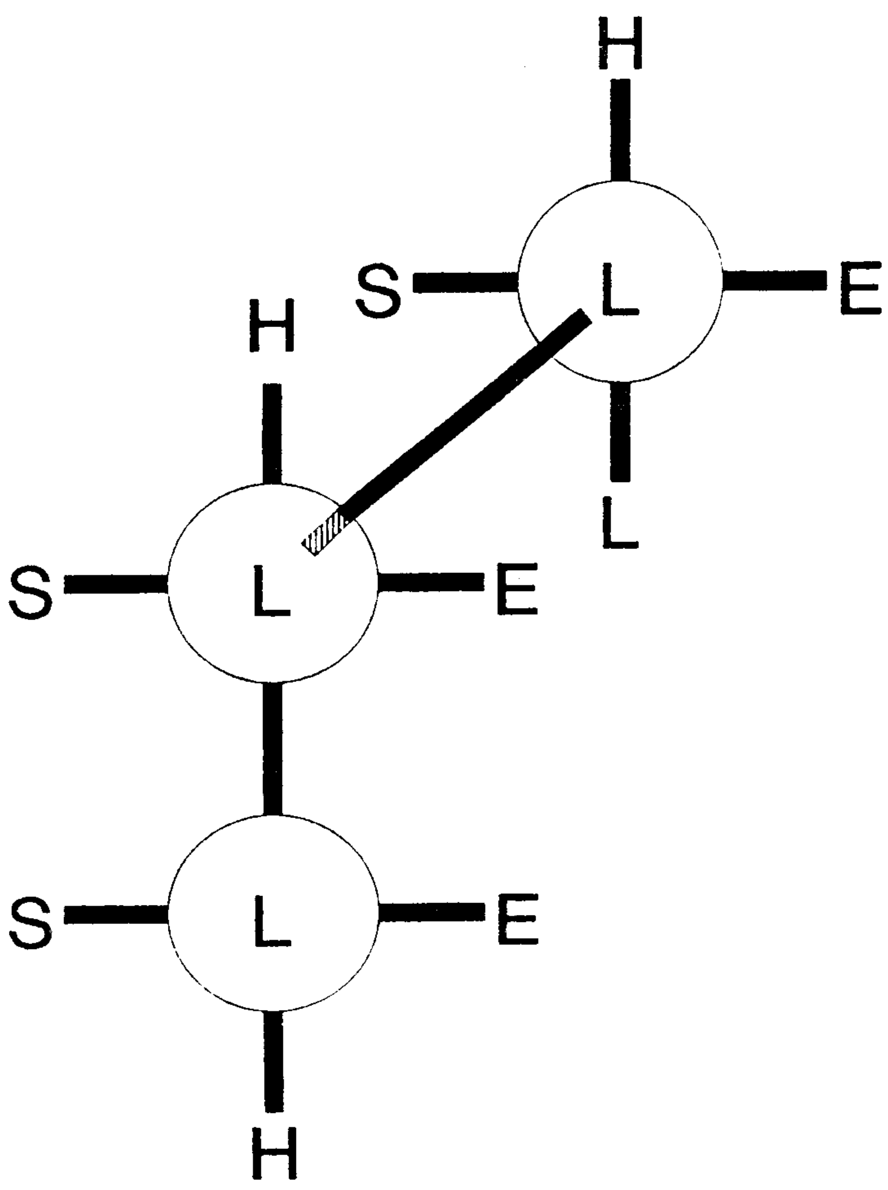

Figure 8-Error! No text of specified style in document.**-5: Modified SHEL Model**

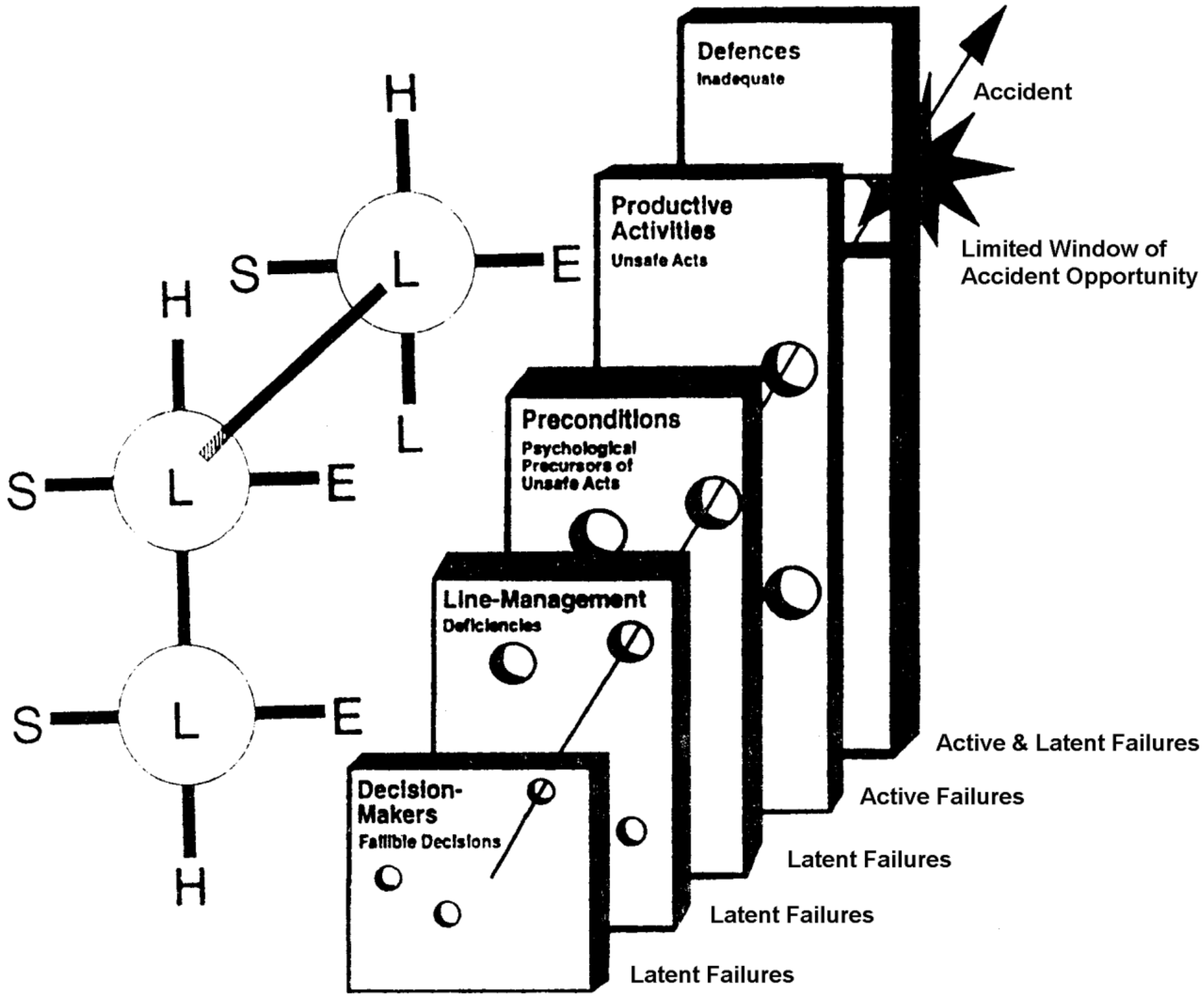

Figure 8-Error! No text of specified style in document.**-6: SHEL and Reason Hybrid Model**

The last unsafe act precipitating the occurrence often provides a convenient starting point for reconstruction of the occurrence.

For example: Following Steps 1 and 2, an investigator determines that one of the unsafe acts was the failure to complete a checklist item.

Note.— This example will be used and built upon throughout this section to illustrate the process.

The data collected during an investigation (i.e. events and circumstances) can be organized, using multiple components of the modified SHEL model, into a framework surrounding an occurrence template (in this case the accident scenario), based upon the Reason model. In this way, each occurrence can be described by a unique framework of events and circumstances, the investigator being interested in identifying those which constitute the occurrence's unsafe acts/decisions and conditions.

Step 4 - Identify error or violation type

Step 4 is initiated for each unsafe act/decision by posing the simple question, "What is erroneous or wrong about the action or decision that eventually made it unsafe?" (Refer to 8.2.5.2.8 for elaboration of the terms used throughout this step.).

The identification of the type of error or violation involves two sub-steps. (See Figure 8-19.)
1) *Unintended or intended action.* First, determine whether the error or violation was an unintended or intended action.
2) *Error type or violation.* The second sub-step is the selection of error type or violation that best describes the failure, keeping in mind the decision regarding intentionality. There are four potential error/adaptation categories, i.e. slip, lapse, mistake and violation.

For example: Continuing with the unsafe act described above, the investigator determines that the unsafe act of not completing a checklist item was unintentional and that it was due to a slip because the operator did not attend to a step in the sequence.

Step 5 - Identify failure modes

In Step 5, the focus is now placed on the decision that eventually led to the erroneous action or decision identified in Step 3. This is accomplished by placing the errors (slips, lapses and mistakes) and violations into the context of performance (behaviour), i.e. how was one performing at the time of the failure?

The GEMS (Generic Error Modeling System) framework facilitates the linkage of an error/violation to an individual's level of performance at the time the failure occurred. By following through to the next step (refer to Figure 8-20), one can begin to understand how errors and violations can have their roots in common behavioural failure patterns (i.e. failure modes) and are not necessarily the result of irrational behaviour.

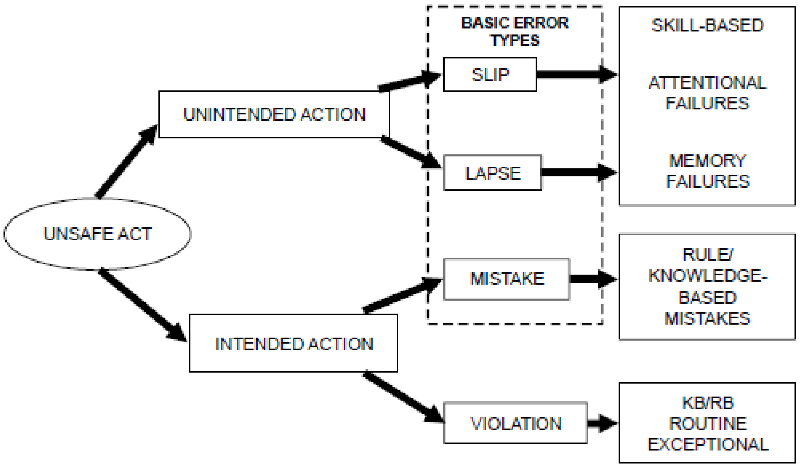

Figure 8-7: The GEMS Framework (adapted from Reason, 1990)

Recalling from 8.2.5.2.16 to 8.2.5.2.20, the error types and violations are matched against three categories of behaviour, resulting in the following:

1) skill-based slips and lapses;
2) rule-based mistakes; and
3) knowledge-based mistakes.

Within each level of performance (i.e. behavioural category), there are different ways or modes a failure can occur (refer to Figure 8-20 for general descriptions of these failure modes). The errors and violations identified in Step 4 can be related to the failure modes as demonstrated by following a given pathway from Figure 8-19 to Figure 8-20.

For example: Having determined that the unsafe act of not completing a checklist item was unintentional and the error type was a slip, the investigator matches the error type to the performance level and determines that the operator was in skill-based behaviour. The failure modes that occur in skill-based behaviour are listed in ICAO Doc 9756 Part III Appendix 1 to Chapter 16. In the example, the investigator, having pieced together the accident scenario, knows that, while carrying out the checklist procedure, the pilot was contacted by ATC and given a departure clearance. The investigator then identifies that one of the failure modes at the skill-based level is omission following interruption which is characterized by a required check being interrupted by some external event. In this failure mode, the original action sequence, i.e. carrying out the checklist procedure, continues, but with one or more of the items omitted. In the case of the example, the two tasks, monitoring the checklist and copying out the departure clearance, competed for the same attentional resources and checklist monitoring suffered.

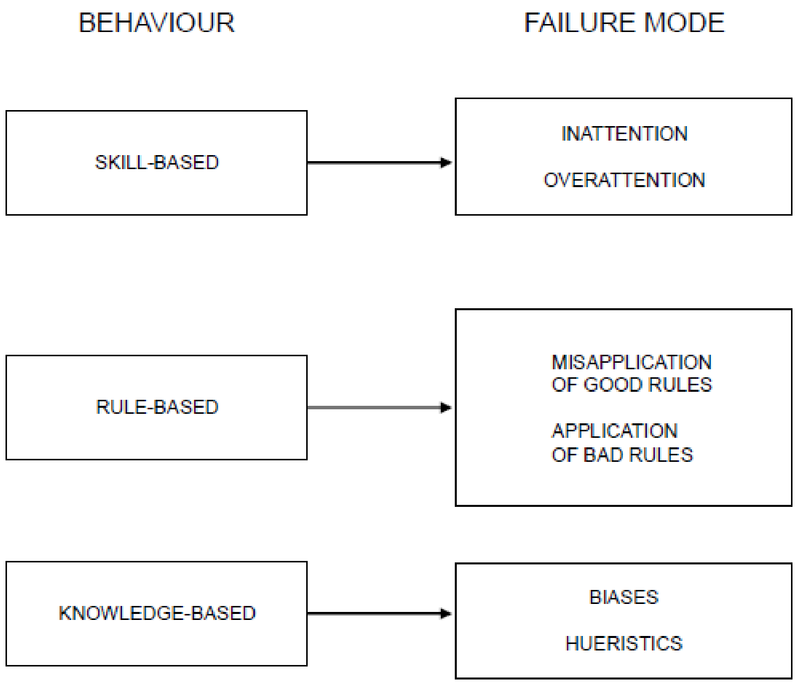

Figure 8-8: Breakdown of behaviour into failure modes

Step 6 - Identify behavioural antecedents

In Step 5, the focus was placed on the identification of failure modes which described erroneous decision-making or unsafe acts. To uncover the underlying causes and contributing factors behind the decision of an individual or group, it is important to determine if there were any factors in the work system that may have facilitated the expression of the given failure mode (and hence the error/violation and the unsafe act). These factors have been termed behavioural antecedents. The behavioural antecedents can be found by examining the work system information collected and organized using the SHEL, Reason, or LUC frameworks in Steps 1 and 2. The re-examination of these data again emphasizes the iterative nature of this investigative process where it may even be deemed necessary to conduct further investigations into the occurrence.

The three performance or behaviour levels can be broken down into common behavioural failure patterns or modes of failure. Descriptions of these failure modes are provided in ICAO Doc 9756 Part III Appendix 1 to Chapter 16.

For example: In re-examining the data gathered, the investigator discovers one of the behavioural antecedents is the design of the checklist itself. The checklist is paper; there are no aids incorporated into the checklist that will enable the pilot to keep track of the checklist sequence. In the absence of such aids, the onus is on the pilot to ensure that an item is not missed. By identifying the design of the checklist as problematic, the investigator has uncovered a latent unsafe condition in the system.

Such latent unsafe conditions in organization and management are the behavioural antecedents to unsafe acts and decisions by operators and maintainers. They represent potential hazards which can be systematically identified, validated and corrected.

Step 7 - Identify potential safety problems

At Step 7, the investigator flags those unsafe latent conditions that occurred naturally or those that occurred as a result of a fallible decision as potential safety problems. For the most part, the identification of potential safety problems is based extensively on what factors were identified as behavioural antecedents. Once again this underscores the importance of the application of a systematic approach to Steps 1 and 2 of the process which sets the foundation for the subsequent analysis steps.

Where appropriate, the potential safety problems can be further analyzed to identify safety deficiencies and recommendations for safety actions.

Summary

The Integrated Process for Investigating Human Factors was developed as a tool to be use by investigators and analysts to facilitate the identification of direct and underlying unsafe conditions in transportation occurrences. The frameworks, which provide the foundation for the process, were drawn from the human factors literature since the human element has been identified as a significant contributor to occurrences. The final step of the process is the identification of potential safety problems which, in turn, may be used to identify systemic safety deficiencies.

8.2.5.3 Investigative Activities

Gathering information

8.2.5.3.1 The success of the human factors investigation depends largely on the quantity and quality of the information collected. As each occurrence is different from the other, the investigator will need to determine the type and quality of data to be collected and reviewed. As a rule, the investigator should be over-inclusive in gathering information initially and eliminate superfluous data as the investigation unfolds.

8.2.5.3.2 Use the SHEL conceptual model previously described as a tool to orient the data collection phase. In general, collect facts that will allow you to:

a) construct a history of all significant behavioural events known to have occurred;
b) thoroughly examine and analyse the SHEL interfaces to determine if and where breakdowns existed;
c) determine what might have influenced or motivated a particular action, of all persons involved in the occurrence; and
d) fully support the existence of an identified safety deficiency.

Sources of information

8.2.5.3.3 Information relevant to an aviation occurrence can be acquired from a variety of sources. Primary sourcesrelating specifically to human factors include hardware evidence, paper documentation, audio and flight recorder tapes, interviews, direct observation of aviation personnel activities and simulations. Secondary sources include aviation occurrence data bases, reference literature and human factors professionals and specialists.

a) Primary sources

1) Hardware evidence is most often associated with the aircraft but may also involve other work stations and equipment used by aviation personnel (e.g. air traffic controllers, flight attendants, aircraft maintenance and servicing personnel). Specific sources include aircraft wreckage, similarly configured aircraft, manufacturer's data, company records and logs, maintenance and servicing equipment, air traffic control facilities and equipment, etc.

2) Paper documentation spans the complete spectrum of SHEL interfaces. Consider the following list of documents:

Personal records and logbooks;
Certificates and licences;
Company personnel and training records;
Aircraft flight manuals;
Company manuals and standard operating procedures;
Training manuals and syllabi;
Company training and operational schedules;
Regulatory authority records;
Weather forecasts, records, and briefing material;
Flight planning documents;
Medical records; and
Medical and post-mortem examinations.

3) Flight data recordings and ATC radar tapes are valuable sources of information for determining the sequence of events and examining the liveware-liveware interfaces. Within airlines using flight recorder monitoring programs, there can be a wealth of information about

crew's normal operating procedures. In addition to traditional flight data recordings, new generation aircraft have maintenance recorders and some electronic components with non-volatile memories that are also potential sources of information. Audio (ATC and CVR) recordings are invaluable sources of information about the liveware-liveware and liveware-hardware interfaces. In addition to preserving personnel communications, audio recordings can also provide evidence on the state of mind of individuals, and possible stress or fatigue. It is essential, therefore, that persons familiar with the crew listen to the recordings to confirm the identity of the speaker and to indicate any anomalies in speech pattern or style. It is also essential that individuals knowledgeable about the specific crew operating procedures listen to the recordings to provide a more complete picture of crew activities that are non-verbal.

4) Interviews conducted with individuals both directly and indirectly involved in the occurrence are also important.

Consider the following persons to interview:

Flight crew
Other crew members
Air traffic controllers
Flight attendants
Passengers
Eyewitnesses

Ground handlers
Weather briefers
De-icing personnel
Dispatchers
Baggage handlers
Aircraft maintenance engineers

Company owner
Chief pilot
Instructors
Other company pilots
Supervisors
V.P. flight operations
Chief instructor
Check pilot
Former employers

Chief of maintenance
Technical specialists
Maintenance engineers

Flight test examiners
Auditors
Airworthiness inspectors
Other regulatory authorities

Physician
Aeromedical examiner
Friends
Psychologist
Co-workers
Family members

Knowledge gleaned from such interviews can be used to confirm, clarify, or supplement data from other sources. In the absence of measurable data, interviews become the single source of information, and investigators therefore need to be skilled on interview techniques. Guidelines on interview techniques are contained in Appendix 2 of ICAO Human Factors Digest No. 7 (Cir 240), *Investigation of Human Factors in Accidents and Incidents.*

b) Secondary sources

1) Not all human factors factual information is gathered in the field. After the field phase of the investigation, additional information about human factors may be collected, facilitating analysis of the factual information collected in the field. These secondary data come from several sources.

2) Direct observations of actions performed in the real environment can reveal important information about human factors. Observations can be made of the following:

Flight operations activities
Flight training activities
Maintenance activities
Air Traffic Control activities

3) Simulations permit reconstruction of the occurrence and can facilitate a better understanding of the sequence of events which led up to it, and of the context within which involved personnel perceived the events.

4) Computer simulation can be used to reconstruct events by using data from the flight recorders, air traffic control tapes, and other physical evidence.

5) Often a session in an aircraft flight simulator or reconstruction of a flight in a similar aircraft can offer valuable insights into the circumstances that led to an occurrence. Participation in simulations by personnel involved in the occurrence events can trigger recollection of important information which would otherwise not come to light.

6) Aviation safety databases containing accident/incident data or confidential reporting systems and databases maintained by some aircraft manufacturers are useful sources of information directly related to the aviation operational environment. Examples are ADREP (ICAO), STEADS (IATA), CASRP (Canada), ASRS, and ASIS (United States), CAIRS (Australia), CHIRP (United Kingdom).

7) Investigators should use databases with caution, however, being sure to know its source and target populations as well as its limitations. They should be familiar with the vocabulary used in a specific database, as no single set of key words is common to all databases. Coding and data entry criteria differ between various databases, which may affect the meaning of retrieved data. Appendix 4 of ICAO Human Factors Digest No. 7 (Cir 240), *Investigation of Human Factors in Accidents and Incidents* provides a more detailed discussion of databases and their application to the investigation of human factors.

8) Literature reviews can be an important source of information. Consulting reference material can help to do the following:

i) Identify how a given human factor may affect performance;
ii) Relate the information found in the field to what is known of human behaviour in similar circumstances; and
iii) Organize the information gathered in the field in a logical way.

9) It should be noted that basic psychological and sociological references can be good sources of information about general human performance, but they seldom address human behaviour in conditions comparable to the aviation operational environment. In recent years, professionals in the human factors field have provided some valuable material addressing aviation operational issues. Some aviation research agencies will, on request, provide literature review services on selected topics. Additional references can be found in ICAO Human Factors Digest No. 7 (Circular 240).

10) At any time during an investigation, investigators must be willing to consult professionals outside their area of expertise. These professionals include, but are not restricted to, the following:

i) Medical officers — to analyze the impact of any medical condition found in the flight crew or other relevant personnel;

ii) Psychologists — to analyze the impact of environmental, operational, and situational factors on motivation and behaviour;

iii) Sociologists — to evaluate the factors that affect interactions and performance;

iv) Sleep researchers and professionals — to evaluate the quality of rest available to the individual, and the impact on performance of a particular work-rest duty cycle or of circadian factors; and

v) Ergonomists — to assess the effect of design and layout on the user.

Data gathering guidelines

8.2.5.3.4 The following data gathering guidelines on the gathering of Human Performance information are based on the SHEL and LUC frameworks. These guidelines were designed to offer:

a) some suggestions on how performance can be altered by these factors; and

b) some guidance on areas to examine for sources of evidence.

8.2.5.3.5 The following description of the SHEL components and interfaces will help investigators collect data to achieve a thorough human factors investigation.

a) *Liveware — The Individual*. The liveware component — the individual — is the centerpiece of the SHEL model. The data that should be collected to address this central component can be broken down into four categories: physical, physiological, psychological, and psychosocial.

1) *Physical factors* deal with the physical limitations of the individual. Determine:

— Was the individual physically capable of performing the required actions and movements?

Physical limitations influence the ability to see, to act, to move, to reach, and to grab. Consider factors such as:

Age	Sex	Weight

Height	Build	Strength
Coordination	Sitting height	Functional reach
Leg length Shoulder	width	

— Was the individual's performance affected by visual, auditory, or other sensory limitations?

Visual limitations might have:

Caused illusions and disorientation.
Limited the ability to perceive traffic.
Influenced judgment of take-offs and landings.
Impaired the reading of instruments or charts.
Caused objects to be missed due to improper focus or empty field myopia.

Some visual limitations are:

Visual threshold Visual acuity
Speed perception Depth perception
Light adaptation Peripheral vision
Glasses, contact lenses Empty field myopia

Hearing or other sensory limitations are:

Auditory threshold (hearing)
Vestibular (acceleration and balance)
G-tolerances
Smell, touch
Kinesthetic (detection of 'movement through muscles'), might cause misunderstanding and illusions.

2) *Physiological factors* deal with the individual as a complex organism encompassing a large array of systems. Determine:

— Was the individual physiologically fit to perform the required task?
— How did physiological fitness, or lack of, influence the person's performance and judgment?
— How did the person's ability to handle diseases, fatigue, or stress affect judgment and behaviours?
— Was the individual affected by any deprivation of any type of physiological need?

Nutritional Factors

— Did nutritional factors affect the individual's ability to:
Respond to an action?

Resist fatigue?
Concentrate on the task?

— Did the individual lose weight recently?

— Was the person on a diet? Consider factors such as:
Food intake in last 24 hours
Hours since last meal
Dehydration

Health

— Was the individual's performance affected by any disease, pain, or dental condition?

— Was the individual physically fit for the task?

— Was the person pregnant?

— Was the person obese?

— Did the individual give blood recently?

Stress

— How did the individual's ability to handle stress affect his/her actions and behaviour?

Emotional signs of long-term stress may include:
Apathy or anxiety (restless, agitated)
Irritability (oversensitive, defensive, arrogant)
Overcompensation (denial, exaggeration, overworked)

Behavioural signs may include:

Withdrawal (social isolation, reluctance to accept responsibilities)
Acting out (alcohol abuse, gambling)
Physical (neglected appearance, tardy)
Infractions (legal, at work, debts)

Smoking

Smoking might cause:
Reduced dexterity
Impaired vision
Affect the judgment of time
Irritability and frustration if deprived

Lifestyle

— How does this person usually behave with others?
— Was there a recent change in lifestyle, in activities, in friendships? What triggered it?
— Could it be a way of coping with stress and pressures? What were those pressures?

Fatigue

Short-term (acute) fatigue could be influenced by:

Amount of sleep (crew rest, nap duration)
Food intake
Nature of activities (activity level)
Nature of tasks (skill fatigue)
Stress level of the last 72 hours
Duration of flight

Long-term (chronic) fatigue might depend on:

Work schedule, leave periods
Circadian disrythmia (jet lag)
Ability to cope with stress
Sleeping patterns, deficit, disruption
Nature of activities
Family and work stressors

Fatigue might have had an impact on:

Short term memory (forgetting)
Vigilance and concentration
Ability to make decisions (limits the choices)
Performance (lower standards, tendency to take shortcuts, taking undue risks)
Stress coping
Ability to perceive and visualize traffic
Ability to hear communications
Job motivation

Alcohol/drugs
Consider:
Over-the-counter medication
Prescriptions
Illicit drugs

Cigarettes, coffee, others
Addiction, hangover, impairment

Alcohol and drugs might have:

Caused drowsiness or dizziness
Affected coordination and vision
Reduced mental functions and sensory perceptions

Incapacitation

Partial incapacitation could be hard to detect. It could be caused by:
Carbon monoxide or food poisoning
Medical conditions
Decompression, diving, trapped gases
Nauseating and toxic fumes
Motion sickness

Partial incapacitation could have resulted in a wide range of symptoms such as:

Hyperventilation, hypoxia, anoxia
Dizziness, loss of consciousness
Lack of concentration
Fixation
Decrease in mental functions or sensory perceptions

Illusions

Several types of illusions could be induced by the environment.

Visual illusions:
Black hole
Flicker vertigo
Autokinesis
Circular or linear vection
Geometric perspective
Landing illusions

Vestibular illusions:

Somatogyral — the “leans”.

Somatogravic — coriolis
Elevator — “giant-hand”

Document the environmental conditions at the time of the occurrence:

Geographical peculiarities of that location
Phase of flight and forces involved (FDR or ATC recordings)
Instrument monitoring and actions

3) *Psychological factors* determine what individuals bring with them to work situations as a result of heir knowledge and experience with the task and their mental capabilities. Included are training, experience, and planning; perceptions, information processing, attention span, and workload; personality, mental and emotional state, attitudes and mood. Determine:

Information Processing

— Did the information to be processed exceed human or the individual’s own limitations (mental capacity)?
— How many “chunks” of information was the individual presented with (short-term memory capacity)?
— Did it induce some biases, poor judgment or inappropriate decision making?
— Did the nature of information processing cause an increase in workload?

Possible signs include:

Focus on a few alternatives
Fixation, channelized attention
Forgetting
Lack of timing and coordination

Perceptions

— What was the individual’s perception or mental model of the task to be performed? Was it accurate?
— Did the individual suffer from any misperceptions, delayed perceptions or illusions caused by either the visual or vestibular system, or circumstances surrounding the flight?

Consider different types of disorientation:

Geographic

Spatial
Temporal
Visual
Situational awareness

Consider the reaction time to:

Detect something
To make an appropriate decision, and
To take an appropriate action

Attention

— Did the level of attention required exceed the individual's own limitations?

Consider the following phenomena:

Attention span
Inattention (general, selective)
Distraction (internal, external)
Channelized attention
Vigilance, boredom, monotony
Habit pattern interference, substitution
Time distortion

Look for evidence of:

Improper actions or improper reaction time
A failure to notice or to react to an event
An improper prioritization of tasks to be performed

Workload

Determine if the crew, by their own actions, decreased or increased the perceived level of workload.

High workload has been known to cause:

Disorganization, fixation, stress/panic
Incorrect prioritization of tasks
Task saturation
Task shedding

Improper decision making
Loss of situational awareness

Low workload could have caused:

Boredom
Inattention
Complacency
Lack of monitoring

Attitude
— What do the facts indicate about the individual's attitudes toward work, the mission, others, and self?
— How did attitude influence motivation, quality of work, decision-making or judgment?

Consider how the following might have affected the individual's performance:

Mood
Motivation
Habituation
Attitude
Boredom
Complacency
Overconfidence

Consider expectations such as:

Mind set
Expectancy
False hypothesis
Desire to get home
Determination to press on
Risk-taking

Mental/emotional state

— Was the individual psychologically fit for the task?
— Did the individual's mental and emotional state influence his or her approach to the situation?

Consider factors such as apprehension, arousal level, self-induced mental pressure and stress as possible performance limiters.

Look for signs of panic, stress, anxiety, including:

- Fixation, gazing
- Tone of voice
- Precipitate or very slow reactions

Experience/recency

— Was the individual's experience, knowledge, and training sufficient, relevant, and applicable to the situation?

Consider the individual's overall or recent experience:

- In the position
- In the aircraft
- For the mission
- On instruments
- With the procedures
- In the environment (night, aerodrome, routes)

Inadequate overall or recent experience has been known to:

- Reduce the person's confidence
- Raise the stress level
- Result in incomplete/inappropriate actions
- Increase the perceived workload level

Knowledge

Determine how much the individual knew about the aircraft, the systems, the procedures, or the environment.

— Did the individual's skill and airmanship have an impact on the occurrence?

Lack of knowledge might:

- Reduce confidence
- Induce confusion
- Result in inappropriate and/or incomplete actions

Training

— Was there a relationship between the occurrence and the type of training received?
— Were there any indications of negative or positive transfer?
— Were weaknesses observed during training similar to the circumstances surrounding the occurrence?
— Was the individual's training sufficient, relevant, and applicable to the situation?

— Consider different types of training:

Initial ground and simulator
Line
Recurrent ground and simulator

Planning

Limited planning might have resulted in incomplete or inaccurate information which might have biased decision making and judgment.

— Did the amount of planning (pre-flight or inflight) reflect the crew or management attitudes towards the flight?

4) *Psychosocial factors* deal with the pressures brought to bear on an individual by the social system (non-work environment). Included are events and stresses (e.g. a death in the family or financial problems) as well as relationships with others (friends, family, peers). Determine:

— Did psychosocial factors motivate or influence the individual's approach to a situation or the ability to handle stress or unforeseen events?

To evaluate the pressure and stress levels experienced by the individual, compare the individual's perception of the events against the perceptions of others.

Consider:

Mental pressure
Interpersonal conflicts
Personal loss
Financial problems
Significant lifestyle changes

Family pressure
Cultural differences

b) *Liveware-Liveware Interface.* The liveware-liveware interface is the relationship between the individual and any other persons in the workplace. Staff management relationships also fall within the scope of this interface, as corporate climate and company operating pressures can significantly affect human performance. Data requirements span such subjects as human interactions, communication (verbal and non-verbal) and visual signals. Determine:

Oral Communications

— Did the interaction with other people or the communication in their work environment influence the performance of individuals, their attitudes, their level of stress, their perceived task demands and workload levels?

Consider:

Noise interference
Misinterpretation
Phraseology (operational)
Content, rate of speech
Language barrier
Readback/hearback

— Did verbal and non-verbal communication influence the sequence of actions in an inappropriate and irreversible manner?

Visual Signals

— Did visual signals replace, support, or contradict the oral information?

— Was the individual influenced by another's non-verbal signs (body language)? Body language can direct an action, cause confusion, stress, misunderstanding, or create negative emotions and pressures.

Crew Interactions

Evaluate the crew's interactions, compatibility in terms of personality, experience level and working habits.

— Did the crew work together or against each other?

— Did the crew make adequate use of their crew resources?

Consider the following elements in evaluating the crew:

Supervision
Briefings
Coordination
Compatibility/pairing
Resource management
Task assignment
Age, personality, experience

Worker - Management

Examine the different levels of management: The management level where decisions and plans are formulated, resources are allocated, and instructions are written, and the supervisory level where these actions are monitored and instructions followed.

Determine if management policies regarding personnel issues affect human performance by causing:

Inadequate levels of experience and knowledge
Excessive workload or inadequate attention
Resentment and unhealthy work environment
Unsafe working conditions

Labour relations

— What was the union's influence on workers, management, policies, and work habits?

— Was there a recent company merger? Did it affect seniority, the individual's work, contract negotiations, or policies?

Pressures

Mental pressures due to operational policies can be real or perceived.

— Was mental pressure imposed by fellow workers, by management, by the industry?

To what degree was it felt?

— What were the employee's alternatives?

— What was the morale of the enterprise?

— Was there a high turnover rate?
Supervision

— Were there policies, standards, and quality controls in existence, available, current and adequate?

— Were policies, standards, and quality controls adequately implemented, accepted, monitored, or supervised?

— Was the ratio of supervisors to employees adequate?

— Were supervisors performing other tasks?

Regulatory requirements

— Did management promote an operational environment which defied regulatory requirements?

— What impact did the operational environment have on the employees' decision making and choice of actions?

— Were employees willing or forced to bend the rules?

— Are the standards used and the existing regulations appropriate?

Consider the different tasks of regulatory agencies:

Implementation
Audit
Inspection
Monitoring
Surveillance

c) *Liveware-Hardware Interface.* The liveware-hardware interface represents the relationship between the human and the machine. Data requirements span such subjects as cockpit and workstation configuration, display and control design, and seat design and configuration. Determine:

Switches, controls, displays.
— Were there any similarities, differences, and peculiarities in design or layout which might have affected the individual's information processing characteristics.

Determine the influence of:

Design
Location
Illumination
Colours, markings

Determine the influence of instruments, displays, controls, switches, or alarms on:

Reaction time
Habit patterns
Workload
Action sequencing
Information processing
Disorientation
Confusion

Evaluate how performance was affected by factors such as:

Space
Illumination
Noise
Climatic conditions

Consider the following:

Workspace layout, standardization
Communication equipment
Eye reference position, seat design
Movement and visibility restrictions
Information displays
Alerting and warnings equipment
Personal equipment interference (comfort)
Data link
Operation of instruments (finger trouble)

d) *Liveware-Software Interface.* The liveware-software interface reflects the relationship between the individual and supporting systems found in the workplace. Data requirements span such subjects as regulations, manuals, checklists, publications, standard operating procedures, and computer software design.

Written information
— Were manuals, checklists, maps, or any written documents accurate, readily available and used?

Determine if the format, the content, or the vocabulary was:

Consistent across similar documents.
Easy to use and understand.
Logical and appropriate.

— Did written documents induce errors, increase response time, or generate confusion?
Consider also:

Publications
Regulations
Charts, NOTAMs
SOPs

Directives
Signage

Computers

— Were computer displays or keyboards compatible with each other?

— Did they induce confusion, increase reaction time, or hide blatant errors?

— Did computers increase or decrease workload at the time of the occurrence?
Automation

— How did automation affect the individual's actions and workload, work conditions, attitudes toward work and mental representation of the task?

— How did automation influence the event sequence?

— Did automation increase or decrease workload at critical times?

— Did it induce complacency and boredom and result in missing important information?
Consider:

Task monitoring
Task saturation
Situational awareness
Skill maintenance

Regulatory requirements

— Was the individual qualified or certified for the task?
Consider:

Certification
Qualification in position and on type
Infraction history
License/rating
Medical certificate
Internal

a) *Liveware-Environment Interface.* The liveware-environment interface is the relationship between the individual and the internal and external environments. The internal environment is that of the immediate work area, including temperature, ambient light, noise, and air quality. The external environment includes both the physical environment outside the immediate work area as well as the broad political and economic constraints under which the aviation system operates. Data requirements include weather, terrain, and physical facilities, infrastructure and economic situation.

— Were there any environmental factors which might have led the individual to take shortcuts, or make biased decisions or which might have created illusions by affecting vestibular, visual or auditory perceptions?

— Were there any indications that the weather or dispatch, hangar, gate, or aerodrome infrastructure caused delays leading to shortcuts, reduced safety margins or limitations on the individual's choice of actions?

— Were there economic or regulatory pressures which biased decision-making?

Consider maintenance facilities:

Support equipment
Availability of parts
Operational standards, procedures, and practices
Quality assurance practices
Servicing and inspection
Training
Documentation requirements