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What Happened, and Why: Toward an Understanding of Human Error Based on Automated Analyses of Incident Reports—Vol. I

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March 2006

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First of all, this work represents one of the several products of a long and successful collaboration between NASA and the Office National d'Études et de Recherches Aérospatiales (ONERA) in research on human factors in aeronautical operations and incidents. During 2002–2003, ONERA and the French Ministry of Defense sponsored a one-year stay of one of ONERA's research scientists, Dr. Nicolas Pascal Maille, at the NASA Ames Research Center. The study reported here is, in very large part, the work of Dr. Maille during that stay. I am grateful to Dr. Claude Barrouil and Dr. Laurent Chaudron of ONERA-Toulouse for their constant support and encouragement.

The development of the tools for effective automated analysis of text described in this report has been accomplished by the exceptional team at Battelle's Pacific Northwest Division under the leadership of Dr. Thomas Ferryman, including Dr. Alan Brothers, Ms. Melissa Matzke, Mr. Brett Matzke, Dr. Christian Posse, Ms. Andrea Swickard, and Ms. Amanda White.

The early formative experiments and discussions that preceded this study were heavily based on analyses conducted using the Cinq-Demi GRID methodology referenced in this report. I am very grateful to Cinq-Demi's researchers and developers of the GRID approach, Générals Jean-Claude Wanner, Pierre Lecomte, and Mme. Nicole Wanner, for their contributions and their always-stimulating perspectives on this work.

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1 BACKGROUND

Air transportation, the most rapidly growing mode of transportation, is also one of the safest modes of travel. Nevertheless, the public demands that safety levels continuously improve and that the absolute number of aviation accidents continues to decline, even as air traffic levels increase.

NASA's Aviation Safety Program (AvSP) was initiated in 2000 to develop the enabling technologies that could, if implemented, reduce the aircraft accident rate by a factor of five within ten years and by a factor of ten within twenty years. One of the projects within the AvSP, the Aviation System Monitoring and Modeling (ASMM) project, addresses the need to provide decision makers with the tools for safety improvement by identifying and correcting the predisposing conditions that could lead to accidents. The objective of the ASMM project is to develop technologies that will enable proactive management of safety risk from a system-wide perspective.[1]

A proactive approach to identifying and alleviating life-threatening conditions in the aviation system entails a well-defined process of identifying threats, evaluating causes, assessing risks, and implementing appropriate solutions. This process is not a trivial undertaking. It requires continuous monitoring of system performance in a non-punitive environment; learning from normal operational experience; comparing actual performance to expected performance; identifying the precursor events and conditions that foreshadow most accidents; designing appropriate interventions to minimize the risk of their occurrence; and having a system in place to monitor the efficacy of the interventions.

At each of these stages, airline domain experts, air traffic managers, and other providers of aviation services must make key decisions. The ASMM project provides computational tools that focus the attention of human experts on the most significant events, and that help them identify the factors that distinguish unsafe operations from routine operations. The purpose of the ASMM tools is to convert a bounty of raw aviation operational data drawn from many sources—aircraft flight data recorders, ATC radar tracks, maintenance logs, weather records, and aviation safety incident reports—into insightful interpretations of the health and safety of the National Aviation System (NAS). Computational sciences and information technology can be used to cope with the great disparity of formats and types of these data sources that include continuous and discrete quantitative data and textual data. However, when it comes to making decisions about aviation safety, the best use of computer sciences is to help the human gain insight into operations. Even the most advanced adaptations of information technologies and computer sciences cannot replace the human expert with automated decisions.

Identifying and recognizing precursors of the next accidents pose considerable challenges that are being addressed in many domains, including nuclear, medical, chemical, pharmaceutical, and space missions, as well as aviation (Phimister 2003). Each domain may have its own definition of a precursor, and so it is important for the reader to understand what the authors mean when we use the term throughout this report.

[1] We use the term "system" in this report to include all aspects of air transportation including, but not limited to, air carrier and general aviation operations, air traffic management, training, maintenance, design, manufacturing, rules and regulations, weather, and organizational cultures.

We use the term precursor to mean the *symptom* of a systemic problem that is conducive to human error and that, if left unresolved, has the potential to result in an accident. A symptom is a measurable deviation from expectations or the norm. It is the problem that must be treated, not the symptom.

We need to start with a model to understand the problem. In Section 5, we describe our concept of Scenario as follows:

SCENARIO = {CONTEXT + BEHAVIOR ➔ OUTCOME}

We consider the Context to be that of the last safe state[2], and the Behavior results in the transition to the Outcome. When the Outcome is an anomalous (unwanted or compromised) state, the last safe state is identified as a precursor. A set of our experiments (the first of which is described in Section 8) is directed at exploring the correlations between the categorical features of the Context and of the anomalous Outcomes. Our assumption (yet to be proven) is that such correlations, together with inputs from domain experts, will help us identify those specific categorical features that cause the last safe state to be a precursor. That is, the causal factors of the Behavior produce the transition from the last safe state to the unwanted Outcome. Our concept of Scenario constitutes the basis for the experiments discussed in Sections 7 and 8, and the future directions of this research discussed in Section 9.

The tools developed to date under the ASMM Project for extracting information from data—in particular, quantitative data—have been based largely on statistical analyses. However, as discussed by Pearl (1997), statistical correlation is a necessary but not sufficient condition for causality. Correlations among precursors, anomalous states, and incidents can provide, at best, partial and indirect evidence about causal links. For example, when we explore correlation between anomalies and contextual factors as described in Section 8, we must be careful that we do not lead the reader to believe that these are necessarily causal factors. An example is that incidents associated with Traffic-alert and Collision-Avoidance System (TCAS) alerts will be well correlated with an aircraft being airborne, but we should not conclude that being airborne is a causal factor of TCAS events. A further caution is that we must not come to conclusions based on statistical analyses that may not have included significant operational factors (Simpson's paradox). For example, a comparison of operations at two airports may be skewed quite differently if we include weather. Or to cite another example, a comparison of operations of two make/model aircraft (say, the Boeing 737 and the Airbus 320) may be changed if we included aspects of the flight crews' training experience. Causes cannot be derived on the basis of statistical or functional relationships alone.

It is important that the precursor not be viewed as being synonymous with causality. Recall that we have identified the last safe state as a precursor if (and only if), among its categorical features, it includes those particular factors that cause the Behavior to produce a transition to an anomalous state. It is in this sense, that we use the term "causal factors" to include:

- Conditions *necessary* for the occurrence of a precursor

AND

[2] When we speak of the "state" in this report, and, in particular, in Section 5, we mean the state of the *entire* system.

- Conditions that *increase the probability* of occurrence of that precursor.

Note that the treatment of the causal factors often entails a re-design, a new procedure, *and* new training.

Consequently, in the approach to the study reported here, we are searching for the causal factors of the precursor incident and not for the anomalous consequences, per se. Even more precisely, as discussed in Section 9, we are seeking to uncover those particular causal factors of the precursor that explain why the transition to the anomalous state occurred.

Identifying the precursors of the next accident is a particular challenge in a complex operating environment like that of aviation with many interacting components. People are key components of the aviation system, and human error is frequently cited as a major contributing factor or cause of incidents and accidents. Sixty to eighty percent of fatal aviation accidents are attributed (rightly or wrongly) to human error. (See, for example, Boeing 2002 and 2004.) However, simply saying that one or more of the humans in a system may have made a mistake is not constructive.

The attribution of "human error" is a social- and psychological-based judgment of human performance made in hindsight that is invariably biased by knowledge of the outcome (Woods et al. 1994). However, human performance is relied upon to resolve uncertainties, conflicts, and competing demands inherent in large, complex systems. Consequently, human performance is as complex as the domain in which it is exercised and cannot be judged independently. Human behavior is context-dependent, and little can be understood of the causes of human error without understanding the prevailing as well as the more distal precursor conditions conducive to error. Much depends on being able to determine how complex systems have failed and on the human contribution to such outcome failures. Consequently, our question is, "Why do professional, well-trained, highly motivated operators of the aviation system make mistakes?" Our focus is on uncovering and understanding those precursor conditions that elevate the probability of downstream human errors and that, in turn, may contribute to aviation safety incidents or accidents. Knowledge about these systemic features helps us to understand how they shape human behavior and how to improve the performance of the system.

The ASMM project has developed automated tools for extracting information from both quantitative numeric data, and from qualitative textual data, and for recognizing information from either data source that may be relevant to a particular query. Information extracted from quantitative data sources helps the domain expert understand the objective aspects of *what* happened, and from qualitative data sources to understand the subjective aspects of *why* an incident occurred. Each ASMM tool contributes insights into the complete picture of an event, and supports the complementary processes of causal analysis and safety-risk assessment. Causal analysis and safety-risk assessment, together with analysis of associated costs and benefits, are all required in order for experts to formulate appropriate interventions.

This report describes a conceptual model and an approach to automated analyses of textual data sources that primarily aid the expert in understanding why an incident occurred. Throughout this report, we will make reference to extracting objective as well as subjective information from textual reports. However, our main focus is on understanding why an incident occurred, for which we must rely on the subjective perspective of the reporter of the incident. We rely on other quantitative data sources (e.g., in-flight-recorded data and air-traffic-radar data) and other ASMM tools (Chidester 2001, Chidester 2003, Ferryman 2001, and Statler et al. 2003) to extract the complementary information about what happened.

2 THE CONTEXT OF THIS STUDY

This report explores a first-generation process for routinely searching large databases of accident or incident reports, and consistently and reliably analyzing them for causal factors of human behavior in aviation operations (the *why* of an incident). Incident reports indicate the presence of problems in systems that, if left unresolved, have the potential to result in an accident (Heinrich 1959). The experiential account of the incident reporter is the best available source of information about why an incident happened.

The analysis of textual databases poses several challenges. First, the process is typically labor-intensive and requires high-priced domain expertise. Further, such analyses not only require experts from aviation operations to understand what happened according to the reported incident, but they will often also require experts in human factors to explain why events happened. Unfortunately, current methods for analyzing textual data often focus on what went wrong and what the consequences were, but fail to exploit this primary source of information about why an event happened. Therefore, there is a need for new analytical methods and automated capabilities to help the experts mine these rich and complex textual databases for insight into the causal, contributing, and aggravating factors of an event.

There are two primary sources of aviation experiential, textual reports to which reference will be made throughout this report. One of these is the database of the Aviation Safety Reporting System (ASRS), (Reynard et al. 1986, Chappell 1997, and Connell 1999), which is a collection of nearly 115,000 narratives of aviation safety incidents that have been voluntarily submitted by reporters from across the aviation industry. The ASRS, managed by NASA and funded by the FAA Office of System Safety since 1976, is one of the world's best-known and most highly regarded repositories of safety information. ASRS incident reports have been used extensively for this study, as well as for earlier studies, as a unique "test bed" for evaluating the tools that are being developed under the ASMM Project for processing and analyzing textual data. In addition, this study has benefited from convenient access to knowledgeable ASRS personnel who have developed, operated, and utilized the system to the benefit of the industry.

The Aviation Safety Action Programs (ASAP) are currently generating the other database of textual incident reports on which ASMM tools and methodologies are being tested. The ASAP programs are intramural, voluntary safety reporting programs through which certificated personnel (pilots, dispatchers, mechanics) at participating air carriers report any safety concern they observe, even if it resulted from their own errors. Modeled on concepts and principles first put into place under the ASRS, ASAP reporting and processing are non-punitive and confidential. Under a collaborative agreement with one air carrier, some of the tools and methodologies described in this report are being tested on ASAP reports, but this report will address only the experiments that used ASRS incident reports.

This report describes a data model and related experiments aimed at achieving an automated understanding of the causal factors of the human error embodied in reported incidents. Our approach is not designed to fit any specific incident-reporting system—our methodology must be sufficiently generic to be used with any database of textual reports of aviation incidents—but we are going to refer often to the ASRS because it is representative of all such databases.

There are, of course, many tools already available for searching textual databases. We have considered their applicability to our needs and, in Appendix A, we describe several tools that we tested on subsets of ASRS reports prior to undertaking this study. Others are continually being identified and evaluated in this ongoing study.

2.1 Research Objectives

The intent of this research is to better understand the quantitative and qualitative attributes of an aviation incident, and to identify the respective contributions of their interaction to incident occurrence. The focus of our research is on the contextual aspects of this interaction. Our specific research questions are as follows:

1. What is the fundamental structure underlying an aviation incident? What are the contextual parameters associated with each part of this structure? Which of these parameters can be considered objective (based on observable data), and which subjective (existing largely within the reporter's mind)? Can the parameters used to define the structure of an incident be adapted to an automated clustering process?
2. What are the pragmatic constraints we must consider in undertaking experiments in automated clustering that are based on statistical analysis and that can be used on very large databases of textual reports? Can the similarities highlighted by an automated clustering process be checked for validity and usefulness? How can we use domain knowledge to minimize the domain size that the automated tools must consider?
3. Is there a conceptual paradigm that will allow us to explain the sequential, discriminating factors that constitute the *why* and *how* of incidents in large aviation databases like the ASRS database? Can this description be used to "tune" automated analyses that will identify contextual similarities between groups of incidents?

2.2 Outline of This Research Report

Incident reports are written by operational personnel who try to describe as clearly as they can a situation they encountered having safety implications. The report forms used by the ASRS and the ASAP contain both fixed fields and free narratives. Together they present the story of what happened, how it happened, and, often, some attempt to explain why.

Automated tools for aiding analyses of textual databases must enable efficient retrospective search for any prescribed event, and must also enable discovery of the un-envisioned. One of the biggest challenges of proactive management of risks is to develop the capability to explore data without knowing what we are looking for. The automated tool should be able to extract typical incidents, but it should also be able to highlight atypical ones and describe their differences in a way that is similar to the tools we have developed for analyzing flight-recorded quantitative data (Ferryman 2001). Fundamentally, both of these requirements rely on a capability to extract groups of similar incident reports from a very large database.

In the development of tools for analyzing flight-recorded data, we found that a concept we called the "flight signature" was useful in guiding the automated identifications of similarities among flights. We believed that we needed a similar model to capture the underlying structure of an incident report and to guide the automated analyses of textual data. Our many years of experience reading almost 600,000 ASRS reports[3] led us to developing a model based on a sequence of states and transitions. In Section 3, we will describe the resulting incident model to aid in understanding the structure of incidents.

As stated previously, the incident-report forms have fixed fields that the reporter is expected to complete as well as the narrative in a free-text field. The fixed fields (i.e., the attributes), together with the information the reporter and the ASRS analyst enter into those fields (i.e., the values of the attributes), comprise the codification of the incident report. A coordinated exploitation of the information extracted from both the fixed fields and the free-text fields is necessary to achieve our objectives, and this is discussed in Sections 4 and 5.

Section 5 introduces the concept of a scenario, a simplified subset of the incident model, as a pragmatic approach for guiding automated clustering of similar incidents.

Section 6 presents a summary of the results of the studies described in the previous sections to lay the groundwork for the discussions and experiments in the following sections.

Section 7 describes a limited experiment based on 40 incident reports. The aim was to evaluate what could be expected from a clustering process based only on the taxonomy (i.e., attributes and values) of the fixed fields and the concept of scenario.

Section 8 describes a preliminary experiment to evaluate the capability to identify and cluster reliably on similarities of *what* happened.

Section 9 describes the approach to extract information about why the event occurred, after automatically identifying what occurred, using the scenario model. Our approach is based on the proposal that loss of situation awareness is the behavioral failure primarily responsible for errors in our aviation world.

Section 10 presents a summary of the conclusions of this study and projections of the continuing studies.

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[3] Although the ASRS has received about 600,000 reports in its 28 years of operation, as indicated previously, only about 115,000 of these have been entered into the database. This has been the result of many factors including judgments on significance and multiple reports on the same incident, but, mostly, limitations of available funding.

3 THE INCIDENT MODEL

The management and the exploitation of very large databases of incident reports highlight the need for sophisticated tools to process free text and to automatically classify reports in a way that is meaningful to experts. In order to extract useful information (whether quantitative or textual) from large databases, it is necessary to identify global patterns and relationships to aid decision-making. We need a model with which to guide the automated analyses.

Report narratives embody naturally occurring chains of events and the transitions between events. An incident report is similar to a script of a play: it describes the environment of the action, the protagonists, and the steps (or acts) in the course of the story. In fact, we will introduce the concept of a "scenario" of a report to represent these naturally occurring "stories." The aim of the next section is to define more precisely the elements of this model, in order to highlight concepts that could be used to calibrate automated tools that will extract information about why the incident occurred. We will first define the meanings of the words used in our model.

3.1 Definitions

World: *"An area, sphere or realm (a field of interest or study) considered as a complete environment"* (Collins Dictionary)

The world of an ASRS-like incident report is composed of all the aircraft, people, weather elements, ground equipment, and other factors that have to be taken into account to describe and understand the course of events that happen (the story). <u>The world of the aviation incident report is a subset of the real world</u>. The boundary of this world (i.e., defining what is needed for a complete environment) is always subjective and depends on the granularity of the description and the scope of the understanding that we want to reach. Following are two examples of what we mean by a bounded world of an incident report:

1. A report describes an incident that took place in San Francisco in severe weather conditions. The cause of such weather conditions is the El Niño phenomenon. Nevertheless, El Niño will not be part of the world of this incident, as the aim is not to understand the weather conditions, but the incident that occurred.
2. A report is about an incident in which an air-traffic controller made an inappropriate decision that resulted in a loss of desired separation between two aircraft. Which aircraft have to be taken into account in the world of this incident? Only the ones in conflict? All the aircraft under the control of the controller (because they change the task of the controller)? We will consider only the aircraft in conflict, as all of the aircraft under the controller's direction are outside the bounds of our "story."

The world is changing continuously; therefore, its description has to be dynamic.

Parameters: The world and its evolution are observed and described through parameters. Some parameters are linked to physical measures; others are not. Parameters can be objective (i.e., defined on bases of observable data) as, for instance, flight altitude, or subjective (i.e., the value of the parameter is not a result of observable data) as, for instance, the ASRS report-form entry “passenger misconduct” to describe a world in which a passenger exhibits abnormal behavior.

The choice of parameters adopted to describe the world is crucial, as this choice largely determines which sort of automatic treatment will be possible. Two criteria have to be considered in the selection of parameters: the level of abstraction of the concept embodied by the parameter, and the ability of this parameter to represent “small” variations.

For instance, let us consider a very simple world that consists only of an electric light bulb. We can choose to describe this world using the terminal voltage of this bulb, or with a Boolean parameter (i.e., on/off). The levels of abstraction of these two factors are not the same, and their abilities to describe the evolution of the world for short periods of time are not the same. If we want to have only a “high level” understanding of the evolution of the world (as a pilot might), the Boolean parameter is the better choice. If we want to understand the response of the component to specific electrical signals, the voltage is a better-adapted parameter.

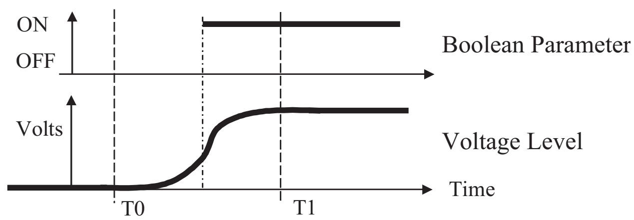

Figure 1. Example of parameter.

State (of the world): <u>The state of the world is the description of the world at a fixed time</u> (a snapshot). The state of the world is given by the values of all the parameters that have been chosen to describe that world. For instance, the state of the “bulb” world at time T0 is “Off” if we describe this world with the Boolean parameter.

Event: *“Anything that takes place, especially something important”* (Collins Dictionary)

When we observe the evolution of the world over a period of time, <u>the evolution of some of its parameters can be described by an abstract concept called an event</u>. An event is defined by a progressive evolution of a set of parameters that “makes sense.” For instance, the evolution of the Boolean parameter between T0 and T1 is typical and allows us to define the event: “switch on.”

As an event describes the evolution of some subset of all of the parameters that describe the world, it gives information about the state of the world before the event, during the event, and after the event.

The level of abstraction of the events defined can be a simple evolution of a few parameters (for instance, our event “switch on”), or a very complex combination of parameters (for instance, an aircraft “takeoff”). Some events, such as “takeoff,” can be decomposed into more elementary events (such as “accelerate,” “rotate,” “liftoff,” etc.), called sub-events.

Transition: *"Change or passage from one state or stage to another"* (Collins Dictionary)

A transition is a combination of events that allows the world to change from one state to another.

Incident: Aeronautical operations are planned according to some rules. These rules try to keep the world in "safe" states and provide criteria to define "unsafe" states (for instance, two commercial aircraft in flight separated by only 100 feet define an "unsafe" state of the world). When the evolution of the world brings it to some "unsafe" state, we have an incident.

<u>An incident is an evolution of the world such that the state of the world reaches some "unsafe" state, and then returns to a safe state.</u>

3.2 The State/Transition Representation of the Incident Model

Reporters of aeronautical incidents describe problems encountered during flight operations. They usually tell them as stories and concentrate on what happened, on the involvement and behavior of people as well as on the important features that help us to understand why these problems occurred. Hence, we assume that the course of an incident is well described by a sequence of states and transitions, and that the whole incident can be decomposed into a sequence of transitions leading the world to evolve from one state to another. Our first assumption is that the essence of the evolution of our world can be captured adequately from the report of the incident, and that this model can be used to tune clustering tools.

<u>Therefore, all the information contained in the report can be associated with a description of a state of the world, or with the characterization of an event that contributes to a transition</u>.

> **Example**: (ACN 81075) "WE WERE ON A VISUAL APCH BEHIND A WDB FOR RWY 28R. AT ABOUT 1000' AGL THE TWR OFFERED US 28L. WE CHANGED TO 28L AND THE TWR CLRD THE WDB TO CROSS 28L AHEAD OF US. THE WDB DELAYED XING AND WHEN WE WERE CLOSE IN THE TWR OFFERED US 28R. WE ATTEMPTED TO CHANGE TO 28R BUT WERE TOO CLOSE IN TO MANEUVER AND SO WE WENT AROUND."[4]

In this example, the first sentence describes a state of the world, while the phrase, "We changed to 28L," describes an event that belongs to the first transition. The evolution of the world as described in this narrative can be represented by a sequence of 4 states, as shown in figure 2.

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[4] For the reader who may not be familiar with aviation abbreviations, following is a literal translation: "We were on a visual approach behind a wide-body for runway 28 Right. At about 1000 feet above ground level, the tower offered us 28 Left. We changed to 28 Left and the tower cleared the wide-body to cross 28 Left ahead of us. The wide-body delayed crossing and when we were close in the tower offered us 28 Right. We attempted to change to 28 Right but were too close in to maneuver and so we went around."

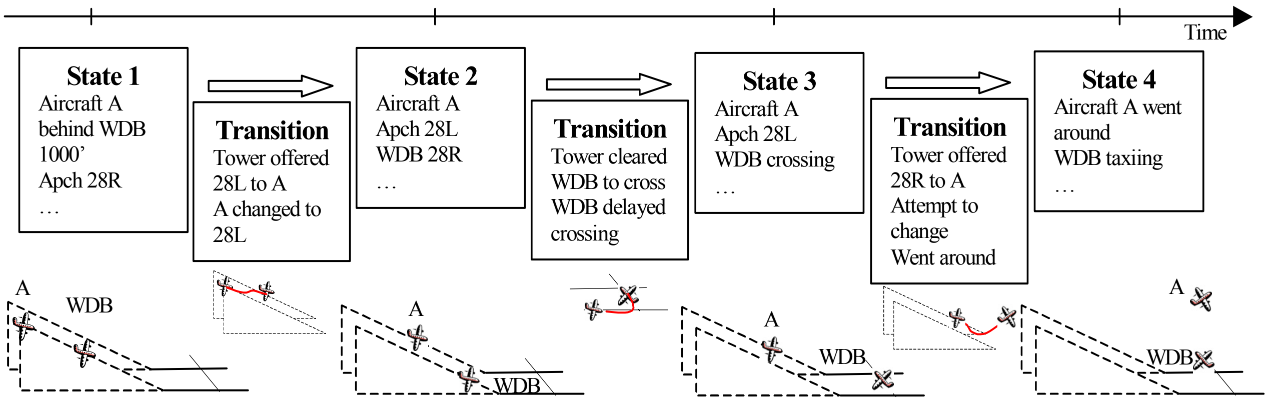

Figure 2. A state/transition decomposition of an incident report.

Nearly all stories (whether in the aviation world or not) can be decomposed into a State/Transition sequence. However, aviation incident reports have other characteristics that we need to exploit. The notion of an aviation incident implies an issue of safety: operational personnel consider that an incident occurs if, for a period of time, the situation is considered as "unsafe" or anomalous. Such notions are not clearly defined and not always interpreted in the same way by all operational personnel. Nevertheless, we can assume that, at a given point in time, aircraft are expected to exhibit a set of Required Properties that define the aircraft (viewed as a total system) as being in a nominally safe state. The Required Properties relate to the aircraft's

- position (altitude, latitude, longitude, airspace occupancy)
- trajectory (heading and projected course)
- flight dynamics (attitude, rotation rates, and speed)
- airframe integrity
- propulsion status
- compliance with clearances, regulations, and SOPs.

This definition implies that there is an expected reference value for each of these properties at every point in time. On the basis of these Required Properties, we can define the following three states of our aviation world:

SAFE: All the aircraft and people (crews, traffic controllers…) and all the key systems (aircraft systems, ILS…) are in a state that approximates normalcy.

COMPROMISED: A person involved in the situation or an aircraft system is in an undesirable state, or undesirable environmental factors impinge upon the aircraft, but for all the involved aircraft their Required Properties are still nominal and the separation between aircraft complies with norms.

ANOMALOUS: One or more of the Required Properties of an aircraft or an involved person is observably not in compliance with pertinent norms.

We can now characterize what we call an aviation incident as follows:

INCIDENT: An incident is a finite sequence of states and transitions such that:

- the first state is safe,
- the last state is safe,
- all the other states are either compromised or anomalous, and
- at least one state is anomalous.

If the state does not return to a safe one, the story is not related to an incident, but to an accident. If no anomalous state is reached, the story is not considered to be an incident. (Figure 3 shows this description of our incident model.) As shown in figure 3, the last unsafe state is often an anomalous one, but this constraint is not required by our definition.

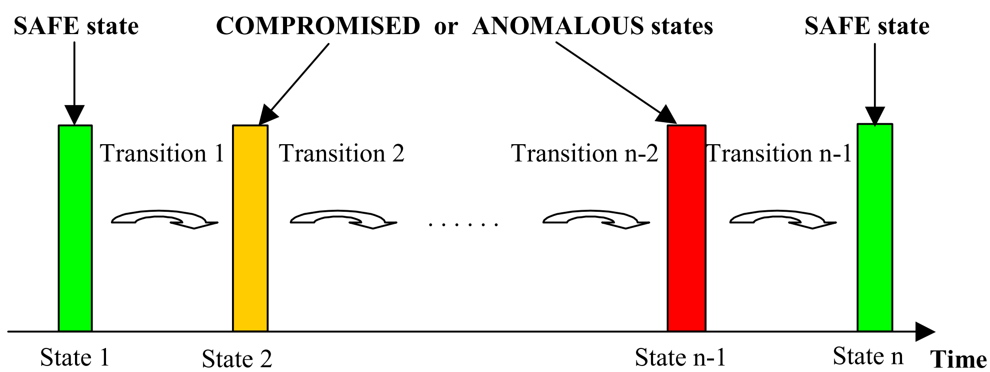

Figure 3. The incident model.

The aim of our incident model is to identify the key components that can be used to tune automated data-mining tools. We are proposing that this representation (i.e., the Incident Model), with its complete descriptions of all of the states and transitions during the evolution of an incident, is a generic model of any and all experiential reports of incidents that occur in our world of aviation. The descriptions of the states and transitions are based on parameters. Therefore, we will need to study the set of possible parameters, and we will discuss this in the next section.

4 PARAMETERS FOR THE DESCRIPTION OF STATES AND TRANSITIONS

We said in Section 3.1 that the world and its evolution are observed and described through parameters. In the example presented in figure 2, states and events have been described in an informal way by sentences or words extracted from the narrative. Choosing a set of parameters that describe a state of the world and a set of parameters that describe a transition will give us a more formal description of each part of such an incident.

A wide variety of taxonomic structures[5] is used in the different accident/incident databases.[6] Our first objective was to identify the taxonomy, together with all of its possible terms and their structure, which is most suitable for reports of incidents in our world of aviation. Each term must map to a parameter in the description of our world in the incident model. The set of parameters that we selected for our study is based on three taxonomic structures underlying three codification forms designed specifically for use with the ASRS database.

- The ASRS codification: The codification of an ASRS incident report is comprised of the set of attributes (the fixed fields) and the values of those attributes (entered by the reporter). This structured set of 'descriptors' is currently used to describe the incident and store it in the database. The codification form is designed for use by operational personnel. One part of the ASRS report form focuses on the involvement and behavior of the protagonists in the "story" reported. In fact, the ASRS report form (NASA ARC 227B – January 1994) encourages reporters to describe the "Chain of Events" (i.e., how the problem arose – contributing factors – how it was discovered – corrective actions) as well as "Human Performance Considerations" (i.e., perception, judgment, decisions; actions or inactions; factors affecting the quality of human performance). Nearly 115,000 incident reports have been codified with this taxonomic structure and are available for further evaluation in the ASRS database.
- The X-Form is another template that was designed to update the codification of ASRS reports. It was designed by ASRS personnel after several years of experience entering the reports into the database and conducting retrospective searches. It contains more fields (attributes) than the ASRS codification, which were intended to improve the descriptions of human-factors issues, but it has never been implemented for routine operational use by the ASRS.
- The Cinq-Demi methodology was developed during the 1980s as a tool for analyzing aeronautical-incident reports from a human-factor's point of view. (A brief description of this methodology is provided in Appendix B.) This methodology involves a structured analysis that focuses on identifying conditions having a high probability of leading to human errors. A codification form for ASRS reports was designed from the perspective of this methodology. Small sub-sets of ASRS reports have been codified using this methodology and are available for further evaluation.

Appendix C contains a description of the study that was made of these three codification schemes. The comparison of their structures and a mapping of all of the parameters used in the three forms were the bases of the following discussion and the definition of the full set of parameters that is provided in Appendix D.

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[5] By taxonomic structure, we mean a structured set of terms that describe some domain or topic. The taxonomic structure provides a skeletal structure for a knowledge base.

[6] As examples, O'Leary et al. (2002) gives examples of the type of parameters used in the British Airways Safety Information System (BASIS) while Murayama et al. (2002) shows some of the Performance Shaping Factors used in a marine incident reporting system.

4.1 High-Level Structure of the Three Codifications

As explained in Appendix C, the structures of the three codification forms for ASRS reports differ in specificities, but their global organizations are quite similar. The information contained in all three can be classified into the following five categories:

1. **Time and Setting**: We group in this category all the information related to the framework of the story (when, where…) and to the fixed entities (facilities…).
2. **Cast of entities**: This category contains information on the persons and all the entities that evolve and take actions in order to create the story.
3. **Anomaly**: This category pertains to all the information that explains why the "anomalous state" is anomalous.
4. **Transitions**: This category is all the information that characterizes a transition in the incident model of states and transitions.
5. **Other**: This category includes any information that cannot be classified into any of the other four categories.

These categories are used only for the codification of a report and not for an in-depth analysis of the incident. They include neither a precise description of the sequence of transitions, nor an accurate time reference. The value of a well-designed codification is, primarily, in its ability to effect an efficient retrospective search of the database so as to produce a minimum of false positives. Nevertheless, worthwhile analyses can be conducted based solely on the information contained in the fixed fields of the form. Figure 4 consolidates the information contained in the three codification forms and shows the overall structure of knowledge of an incident report.

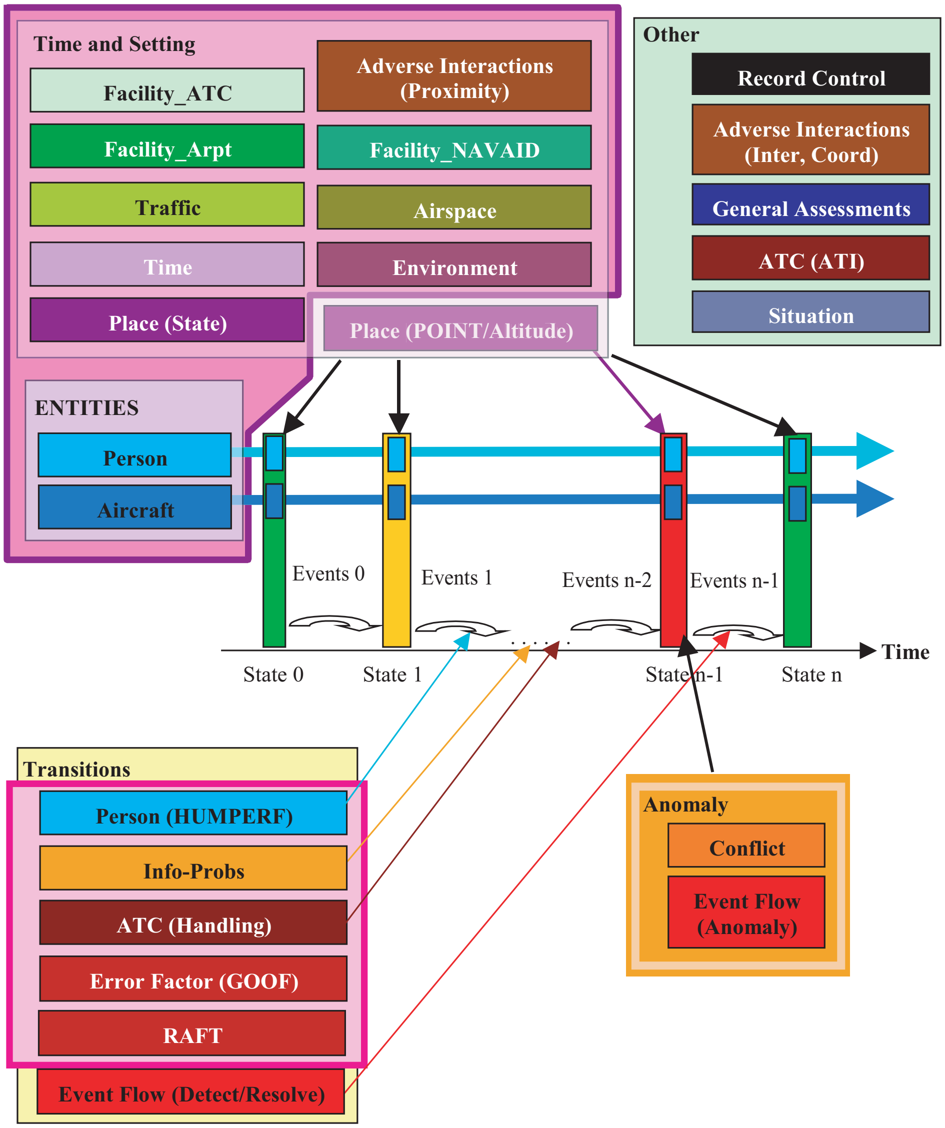

Figure 4. Consolidated structure of ASRS codifications.

4.2 A "Full and Complete" Set of Parameters

As highlighted in Wiegmann and Thaden (2003), most reports are highly informative about ***what*** happened, but give much less definitive information about ***why*** an incident happened. Consequently, there is merit to designing the clustering process so that the first level of automated filtering clusters incident reports on the basis of similarities in what happened. Furthermore, most of the information about what happened is contained in the parameters (attributes and values of the fixed fields) of the consolidated structure of ASRS codification (see the previous section and Appendix C). Consequently, our first objective was to come to agreement on the "full and complete" set of parameters that describe our world. Appendix D discusses the mapping of the parameters of the three codification forms; we assume that merging these parameters results in a nearly "full and complete" set of parameters that describe our world. Also, for every parameter used, we can state if the concept captured is objective or not. We use the following definition: a concept is ***objective*** if its definition can be based on ***observable*** data. All the concepts that are not objective are called ***subjective***.[7]

Our hypothesis is that a full and complete set of objective parameters of an incident in "our" world adequately describes what happened. We further assume that, given a full and complete set of the objective parameters, automated tools could reliably cluster incident reports on the basis of what happened and could, thereby, provide an adequate description of what happened. (The experiments to demonstrate this are discussed later in this report.) In fact, clustering on the *what* may prove to be pragmatically sufficient for an effective retrospective search for similar incidents, even though the explanation of *why* may be quite different for the clusters of incidents. The understanding of *why* the incident happened will rely on subjective parameters and exploitation of the free text. The proposed process to achieve this in a second stage of automated filtering is discussed later in Section 9 of this report. However, first we need to introduce the notion of a scenario and explain how it is used to determine similarity of reports, based on what happened.

5 THE SCENARIO

We use the term "scenario" in the same sense as it is often used in literature or cinematography. We will show how it can be used to define a clustering methodology.

Scenario: *"A summary of the plot and characters of a play or film"* (Collins Dictionary)

Let us begin with an example from literature: "Romeo and Juliet." The scenario of this play could be: "*Two young people love each other, but sociological difficulties (hate between the respective families) thwart their love. They are desperate when they realize the conflict between their families is insoluble, and their despair brings them to their deaths*." A scenario provides a global understanding of a story and often emphasizes the starting and ending points of the story. Several scenarios, more or less detailed, can be given for the same story, and some different stories (e.g., not in the same place, not with the same people…) can have the same scenario.

An aviation incident report can be seen as a story and, as with a play or a movie, we can try to extract from it a scenario. An aviation incident report is the story of the evolution of our world from a safe state, through a sequence of events and states to a compromised or an anomalous state. If we return to our example (ACN 81075) in Section 3.2, its scenario could be: "*A transport category aircraft is on a visual approach to an airport with active parallel runways. ATC changes the aircraft's landing clearance at low altitude and a conflict develops with a taxiing aircraft. The aircraft makes a go-around maneuver*."

The scenario notion can be useful to guiding the extraction of clusters from large databases. Indeed, when the search is not related to a pre-defined specific issue or a pre-selected example report, a

[7] Some of the objective factors may come from the fixed fields of a new codification form while others may have to be extracted from the narrative, but that is not important to this discussion.

meaningful way to build clusters is to group reports with similar scenarios. Identifying the main scenarios in a database should help experts identify major safety issues and obtain clues for designing intervention strategies.

Therefore, we need to have a more accurate definition of the scenario notion. As with a play, the scenario highlights some parts of the story. So the specificities of the story have to be used to define the scenario concept. As shown by the state/transition model of an incident, an incident report has a specific structure that has to relate to the design of the scenario. Let us recall some of the characteristics of an incident:

- It starts with a safe state,
- The first transition leads the world into a compromised (or anomalous) state,
- One of the transitions leads the world into an anomalous state,
- One subsequent transition recovers a safe state.

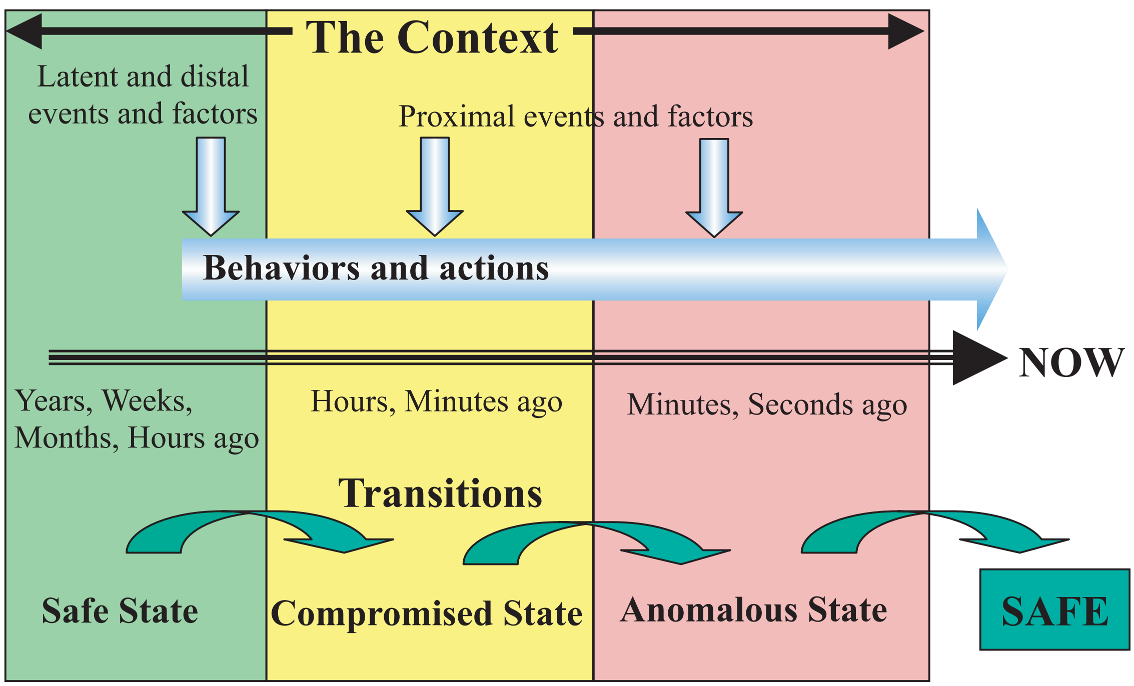

Figure 5. The framework of the scenario concept.

Figure 5 is another representation of an aviation incident that is obviously similar to figure 4. However, we use this representation to make several important points. The initial safe state may extend over a long period of time and may entail latent and distal events and factors, such as organizational culture, laws and regulations, company policies, and education and training, that may influence the behavior of the protagonists. In the time frame of minutes to hours, there may be proximal events or factors such as weather, visibility, traffic, fatigue, and equipment that may influence the protagonists' behavior and the transitions from the safe to a compromised state. In the time frame of seconds to minutes, the safety of the system may rely upon immediate factors of communications between the pilot and the air-traffic controller. The point is that human behavior is context-dependent. As we seek to understand the causal factors of human error and the *why* of the incident, that context extends across all three states (safe, compromised, anomalous). Further, the factors of the context may evolve during the course of the incident and may even be influenced by the actions taken (Woods et al. 1994).

Figures 4 and 5 may well be the representations needed to achieve our objectives. However, they are much too complex to be used as a basis for identifying similarities with automated clustering tools, at least for this initial study. Therefore, based on our experience with ASRS reports, we chose to emphasize three parts of the generic incident model represented in figure 4 for our concept of scenario: the first (safe) state (the beginning of the story); the sequence of states and transitions that lead the world to the anomalous state; and the anomalous state. Thus, the high-level definition of the scenario that has been adopted for this study is:

SCENARIO = {CONTEXT + BEHAVIOR ➔ OUTCOME}

With this simplified definition of scenario:

- The Context fits the exact description of the situation in the last safe state.
- The Behavior contains all the problematic events that occur during the transition from the last safe state to the anomalous state.
- The Outcome describes why the anomalous state is considered as anomalous. It does not necessarily contain all the parameters used to describe the state.

This simplified model may not apply to all worlds and, even for our aviation world, other representations could be stated and will, perhaps, have to be explored in future work. As an example, we could highlight the recovery action and the final safe state in order to study which parameters influenced the recovery process (and so prevented an accident). Also, this model does not provide for the possible changes in context across the three states, as the context of the last safe state is assumed to prevail throughout the incident. Nevertheless, there is merit in starting with the simplest possible model.

The objectives of the first stage of automated analysis are: (1) to identify and describe the scenario of an incident report, and (2) to identify similar scenarios from a large database of incident reports. Both of these objectives benefit from our simplified definition of scenario.

Figure 6 shows the associations between our definition of scenario and the incident model. Figure 7 shows its relationship to the high-level structure and informational categories discussed in Section 4.

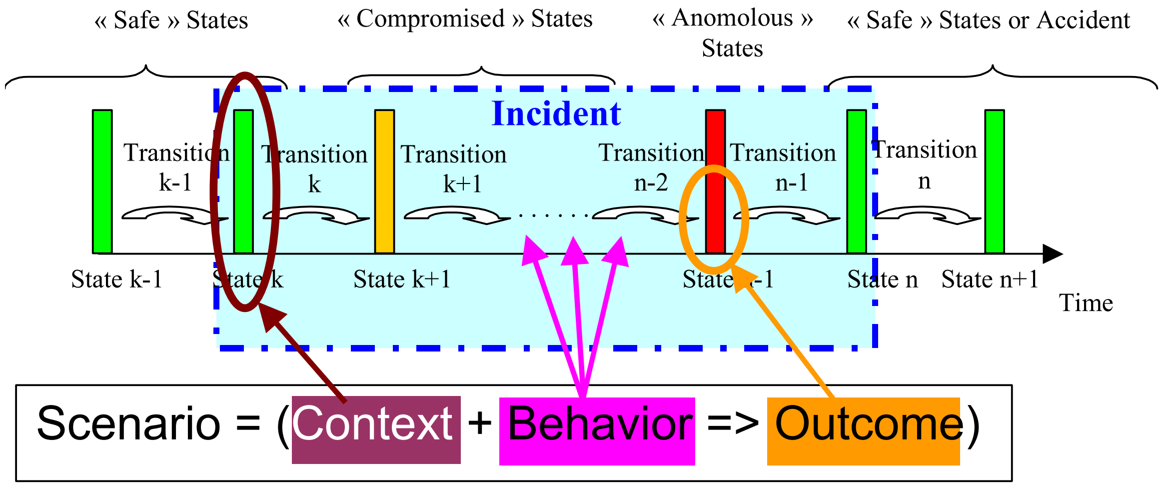

Figure 6. The relation of scenario to the incident model.

We need to focus and guide the automated analyses of textual reports in order to maximize the chances of success with current capabilities. One way is to use domain knowledge to minimize the extent of the world that the automated tools must consider for each incident report, by aggregating the reports in the database. Accordingly, we use "phases of flight" as an aggregating principle because aviation-incident scenarios are likely to be identifiable with phases of flight. We may choose to further constrain the domain by aggregating reports by size or type of aircraft, for example, or by visual versus instrument flight rules, but such aggregations may well be determined by the purpose of the search. Next, we again use domain knowledge to identify the possible anomalous or compromised states for each phase of flight and, possibly, for each aircraft type. (For example, a near-midair collision is not an anomalous state for the taxi-out phase of flight.) Then we identify the subset of the "full and complete" set of parameters (objective and subjective) that could be relevant to, and that could define the states of, any incident in each of these phases of flight.

The specificity of the parameters used to define the scenario's three parts will determine the degree of discrimination that the automated clustering process can achieve: the parameters used to define the Context, Behavior, and Outcome will have to be more detailed and precise if we are interested in distinguishing small differences among incidents than if we are only looking for general categories. Consequently, the scenario is defined by the subsets of parameters that describe the Context, the Behavior, and the Outcome of the incident model that are specific to the "story" of a particular incident report. Thus, not all the parameters used to define a state of the world will be used to define the Context, because not all the parameters of the Context of the initial safe state are important to, or are causal factors of, the Behavior or the Outcome of that "story". In the same sense, the Outcome is described only by those parameters that distinguish this state as an anomalous one.

Therefore, now we have the beginning of a taxonomic structure for the first stage of clustering on what happened. We start with a prescribed subset of incident reports (aggregated, for example, by the phase of flight and by aircraft type), then identify with this subset all of the possible anomalous states, together with the objective descriptors that could possibly be associated with that subset of Outcomes. So, within each aggregation by, for example, phase of flight and aircraft type, we focus on the subset of reports related to each of the identified anomalous outcomes. Finally, we identify all of the other objective and subjective factors that could be relevant to any incident in that sub-subset. This process is intended to minimize the domain that the automated system must consider in this first stage of filtering, and to maximize the information known about the incident. In this first stage of filtering, we have clustered on similarities of the objective parameters that define the Context of the Scenario, together with the similarities of the objective parameters that define each possible anomalous state associated with the Outcome of the Scenario in the aggregated subset of reports. (The experiment described in Section 8 was designed to explore the potential of this first filtering stage on the correlation between the parameters of the Context and each anomalous state.) It is desirable to complete this process before we attempt the next stage of automated analysis of the free text for its implicit (subjective) information about the clusters identified.

An assumption previously stated is that we have adequately defined *what* happened (and, possibly, a bit of the *"how"*) by identifying all of the objective parameters of the Context and the Outcome that existed in a particular scenario. That was the primary motivation for generating the complete list of the objective parameters. However, all of this, so far, is preliminary to our objective of automatically defining the *why*. In the second stage of filtering, we will see if we can isolate the subset of objective parameters of the Context that correlate to Behavior in that Scenario and hence to the causal factors of the Outcome. This process is described in Section 9.

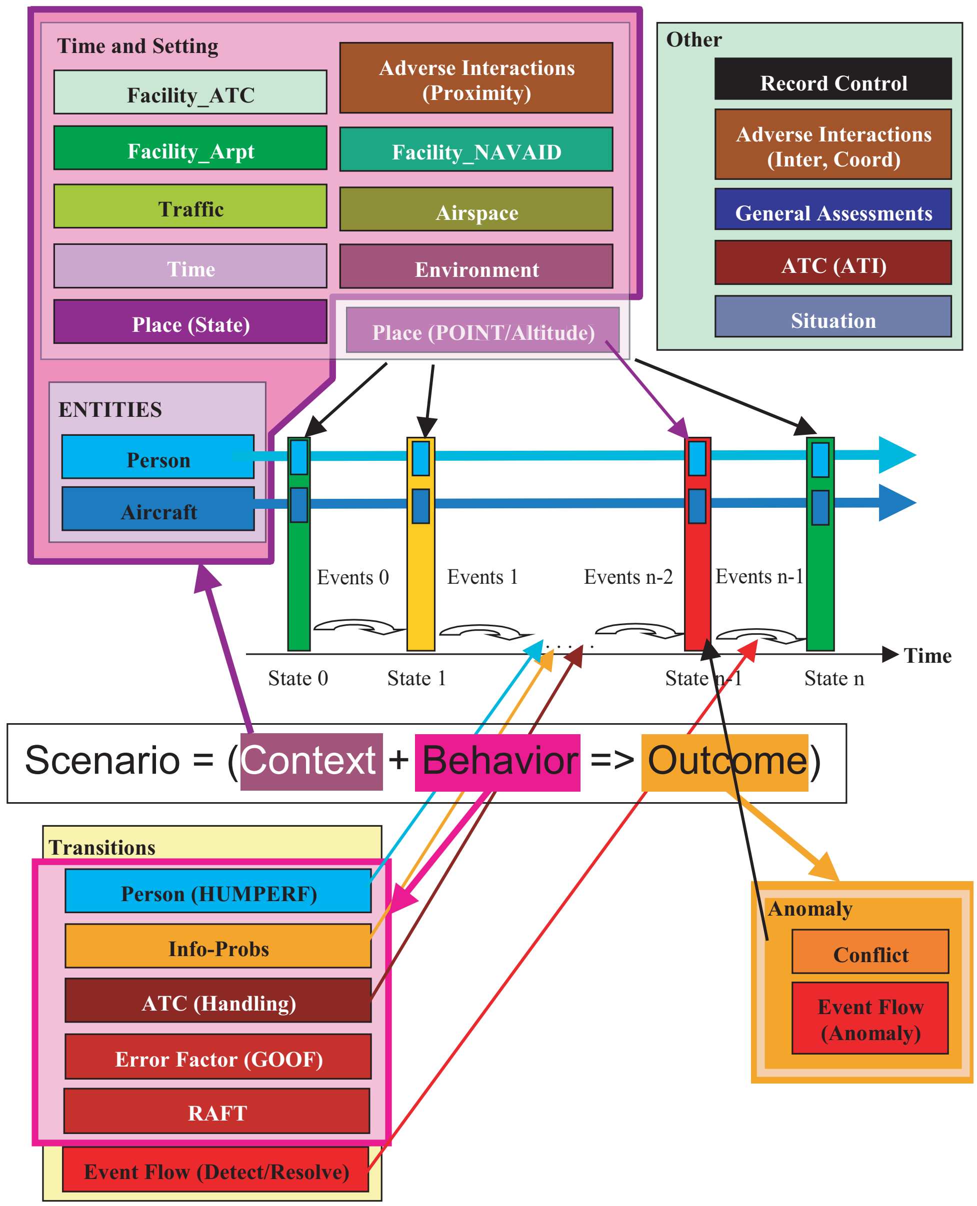

Figure 7. Relations between the scenario and the categories of descriptors.

6 PRELIMINARY CONCLUSIONS

We have shown how we defined a generic structure of information (a taxonomic model) that is adaptable to the description of ASRS-like aviation incident reports. The resulting model of an aviation incident is postulated to be a sound basis for defining similarities among incidents reports. The notion of Scenario has been introduced as a pragmatic guide for identifying similarities based on the objective parameters that define the Context and the Outcome of a Scenario.

We have assumed that it is possible to design a clustering process guided by the structure of the scenario, and that the results will be easier to understand by an aviation expert. We now have the simplified structure of the Scenario. We have identified the “full and complete” set of parameters that define the Context of the initial safe state, and the anomalous Outcome that adequately describes what happened. Automated tools will use the values of these parameters to identify the Scenario and to cluster similar Scenarios from the ASRS database. The potential of this approach is demonstrated in the experiments that are described in Sections 7 and 8.

7 A CASE STUDY

All of the work reported in Sections 3 through 6 was preparatory to implementing an approach to automated clustering that is based on statistical analysis and that can be used on very large databases of textual reports. In this section, we describe an experiment with a different clustering technique that can be used only on small sets of reports, but that enables us to evaluate the model we have proposed. The clustering tool is described in Section 7.1. It entails a methodology based on Formal Concept Analysis (Ganter and Wille 1999) in which it is possible to maintain throughout the clustering process an explicit description of the similarities among the parameters of the reports. This capability will be used to check whether the similarities highlighted by the clustering process are valid and useful. However, there are pragmatic computational limitations to such qualitative analyses, so that only small sets of data (reports times parameters) can be considered. The statistically based tools will be used to study larger sets of reports, but they may hide the meanings of the similarities in a given cluster. As we want first to evaluate the validity of the model, we chose to start with a limited experiment based on an explicit handling of similarities.

As explained previously, we assume that a “full and complete” set of objective parameters adequately describe what happened. In this study, we are going to extract from the set of objective parameters identified previously and in Appendix D, a description of the *what* of the incident in two parts; namely, the “Context” and the “Outcome” of the Scenario as defined in Section 5. Then a set of 40 ASRS reports will be codified in a formal language adapted to the clustering tool chosen (in Section 7.2). We use a two-step clustering process. First, we identify the Outcomes (in Section 7.3.1), and then we analyze the Contexts that are typically associated with each of the Outcomes (in Section 7.3.2). In Section 7.4, we describe a limited study on the *why* that relied upon the Cinq-Demi codification.

Before we present our study of these 40 reports and the results, we will describe how these particular reports were selected from the ASRS database, as well as the clustering tool that we used in the study.

7.1 The Sample and The Clustering Tool

Describing objects by their set of properties is a natural process used in several domains. A “concept” of the domain can be described by a set of objects: the extent, which is a collection of examples of elements that belong to the concept; and the intent, which is the set of their shared properties. For instance, the concept of airplane could be captured by a set of objects such as (B737, B747, B777, A320…) and the set of their common properties (wings, tail, engines, pilot…). Given a set of objects and the set of properties associated with each object, one can automatically extract all the concepts involved. This is the aim of Formal Concept Analysis (Ganter and Wille 1999) based on well defined mathematical foundations. An extension of the FCA formalism called Generalized Formal concept Analysis (GFA) that enables objects to be described by a structured set of properties has been proposed by Chaudron and Maille (Chaudron and Maille 2000), and a tool named Kontex has been developed to identify concepts. Given a set of objects and their properties, the Kontex tool calculates all the possible concepts, shows all the relations between the concepts (generalization, specialization) and describes their similarities and differences by using an adapted graphical interface. That tool is well suited to our experiment as each incident report is directly characterized by a structured set of properties (as described by the taxonomy) and so can be considered as an object of the GFA methodology. The GFA methodology was chosen to conduct the analysis of a sub-set of ASRS reports.

An important step in this experiment was selection of the set of reports to analyze. As the purpose was to use the explicit description of the similarities and differences between clusters developed with the Kontex tool, the number of reports had to be limited both as a matter of practicality in reference to calculation complexity, and for ease in interpreting the results. Based on a previous study (Maille 2002), a set of 40 ASRS reports seemed to be a practical number. Moreover, as we wanted to evaluate whether the taxonomy and the Scenario components supported a meaningful clustering on what happened, we wanted to have in the set of reports a small number of different Contexts and Outcomes in order to have significant clusters. Indeed, if only 40 reports are taken randomly from the database, they will certainly deal with a large variety of different kinds of *what* and it will be difficult to utilize the capabilities of the methodology. Therefore, we decided to focus on reports from the particular experiment that was concerned with "In-close Approach Changes (ICAC)" (Lecomte et al., informal communication)[*]. All of these reports deal with aircraft in the approach flight phase, and so the number of possible anomalies (or Outcomes) is limited. The clustering process would try to reveal finer similarities between groups of reports and possible links between Outcomes (or anomalies) and Contexts. In the ICAC experiment, around 200 ASRS reports had been codified by the Cinq-Demi team and 100 reports had been fully analyzed using the Cinq-Demi methodology of Appendix B. We chose for this experiment the first 40 reports in the Cinq-Demi database that had received a full analysis.

7.2 Formal Codification of the 40 Reports

For the 40 reports, we had both the ASRS and the Cinq-Demi codification available, but not the codification with the complete set of parameters described in Appendix D. We decided to rely on the ASRS codification as much as possible (flight phase, anomaly…), even if the codification is not exactly the one defined in our taxonomy. Then we added to this codification some parameters to describe the traffic, the airport (configuration of the active runways…) because these important parameters are not addressed in the ASRS codification. For these new parameters, we used the taxonomic structure of Appendix D. All these properties that describe the Context and the Outcome of the report are formally captured in a first-order language that is used by the GFA tool.

[*]Lecomte, P.; Wanner, J. C.; and Wanner, N. Late runway changes. Unpublished informal communication, 2002.

As the Cinq-Demi codification was also available, we decided to incorporate the “error-factor” (part of the GOOF grid) in our formal codification. That parameter does not belong to the *what*, but is part of the description of the *why*. It was not the primary subject of this experiment, but will be exploited in Section 7.4.

7.3 Clustering on the What

The *what* is described through various objective parameters that belong to the “Context” and the “Outcome” parts of the Scenario model. Our clustering process starts with the identification of the Outcomes involved in the selected set of 40 ICAC reports. As expected, there are only a few different ones as they were all associated with In-Close Approach Changes. Then for each group of reports associated with a particular Outcome, an analysis of the related Context is conducted.

7.3.1 First Step: Clustering on the Outcome

As stated before, we used the ASRS taxonomy of anomalies as the codification of the Outcome. That taxonomy contains around 60 terms grouped into 13 categories (Aircraft Equipment Problem, Airspace Violation, Altitude deviation…). Each of the 40 ASRS reports was identified with one or more of these Outcomes. With the Kontex tool, the 40 reports were clustered according to their Outcomes. Reports were clustered by each anomaly, and also by each and every combination of the anomalies that had been identified within the set of 40 reports. This resulted in 50 concepts (clusters); a top-down analysis of these concepts was conducted.[8]

The top-down analysis identified “significant” clusters. A cluster was considered significant if (1) it had none or few reports that were shared with other significant clusters, (2) contained a large percentage of all of the reports, and (3) collectively, the significant clusters contain nearly all of the reports.

This process highlighted four main groups of reports based on four anomalies: “Track or Heading Deviation,” “Airborne”, “Ground,” and “Near Mid-Air Collision (NMAC).” We point out that the three anomalies “Airborne,” “Ground,” and “NMAC” belong to the category called “Conflict” in the ASRS taxonomy of anomalies. So, we are able to state that we have identified two main Outcomes in the Scenarios of these 40 reports; namely, reports that deal with a spatial deviation (track or heading) and reports dealing with a conflict. This first stage of analysis also showed that the ASRS anomaly called “Non-Adherence to a Clearance” was often encountered, but it seemed to be a shaping factor in the four main groups identified.

In addition, a set of five reports contained all the reports that were not related to any anomaly of the taxonomy[9] and two exceptions were identified. One exception was linked to an “Aircraft Equipment Problem” anomaly and the other one to an “In-Flight Encounter” anomaly. The following table summarizes the results. Of the five reports that do not belong to any of the four identified anomaly

[8] Readers interested in how such a top-down analysis is performed can refer to the report by Maille (Maille 2002) where a similar analysis is performed for 44 ASRS incident reports.

[9] Some reports in the ASRS database have no identified anomalies but have been entered into the ASRS database because the ASRS experts considered the sequence of events to be interesting from a safety point of view.

categories, four reports are linked only to a problem of non-adherence to a procedure (i.e., a FAR or a clearance) and one report relates to an altitude deviation.

TABLE 7.1. CLUSTERS OF REPORTS TO ANOMALIES

Report #	81075	81871	86908	93410	99699	104417	112293	121190	124655	131917	136038	140893	153742	163469	164717	171178	183215	191370	195089	197451	201970	202728	204530	210692	213428	215480	223672	224291	226934	229858	230893	236595	240786	244851	254361	263097	264593	266620	268296	269162
Track/Hd								*		*	*			*	*									*	*		*			*	*		*				*			
Airborne					*											*	*				*					*		*							*			*	*	*
Ground													*					*																		*			*	
NMAC				*			*															*																		
Other	*	*										*							*													*								
InFlight									*																															
Aircraft																													*											

7.3.2 Second step: Clustering on the Context

In the first step, we clustered the 40 reports by their Outcomes (the ASRS-defined anomalies). In the next step, we wanted to cluster on the shared Context within each significant cluster. This Context was fully described by the objective parameters as they were provided in the codification of each ASRS report. Therefore, we used the Kontex tool once again to cluster on each objective parameter and all combinations of objective parameters within a significant cluster of Outcomes. The idea was to explore all the possible concepts based on the formal codification of both the Outcome and the Context, and to determine whether a specific Context could be associated with each of the four particular Outcomes highlighted in the first step. The main results of this second stage of clustering and the top-down analysis are summarized here.

"**Track and Heading**." The Context shared by the 12 reports identified with this anomaly is: "An aircraft is in the approach flight phase to an open and controlled airport. The aircraft is controlled at the beginning of the incident by the TRACON." In addition, in most cases (in 9 of the 12 reports), the aircraft was in Class B airspace and parallel runways were active.

"**Airborne**." The Context shared by the 10 reports in this category is: "Two aircraft are in the vicinity of an open and controlled airport. One of them is in the approach flight phase." This shared Context by itself was not adequately discriminating, but the analyses showed an interesting group of 6 reports that shared the following properties: "The two aircraft are in the same phase of flight (approach) in the Class B airspace. There is some traffic and parallel runways are active." The four other reports shared only the property of being controlled by the tower.

"Ground." The Context shared by the 4 reports in this category is: "An aircraft is in the approach flight phase to an open and controlled airport. The aircraft is controlled by the Tower." Then further analysis shows that the more common situation (3 reports) is that "there is another aircraft and some traffic." The only report without another aircraft in the Context deals with a conflict between the first aircraft and airport workers on the runway.

“**NMAC**.” The Context shared by the 3 reports identified with this anomaly is: “Two aircraft are in the approach flight phase to an open and controlled airport. Parallel runways are active and there is some traffic. One aircraft is a Medium Large Transport (MLT) and the conflict develops while they fly in Class B and D airspace.”

At first glance, the four Contexts appear to be similar. Let us highlight their similarities and differences. They all deal with “an aircraft in the approach flight phase to an open and controlled airport.” This is not a surprise, as it is a direct consequence of our selection of this particular subset of 40 reports. Therefore the differences in Contexts rely on a finer level of granularity in the descriptions of the Contexts.

We point out, for example, that the three Contexts associated with conflicts (i.e., Airborne, Ground, and NMAC) contain the descriptors “**traffic**” and “**2 aircraft**” but not the descriptor “**TRACON**.” In contrast, the “Track and Heading” deviation category seems not to be directly influenced by the traffic or the presence of another aircraft, but generally starts to develop while the aircraft is still under the control of the TRACON (coordination during the transition of control from the TRACON to the Tower could be a source of Track and Heading deviations). Conflicts, on the other hand, are, as expected, directly related to a problem of traffic and to the simultaneous presence of two aircraft around the airport.

The differences in the Contexts associated with the three conflicts are more subtle. First the NMAC Context is a special case of the Airborne Context (2 aircraft in the same flight phase, traffic, parallel runways, and class B airspace). This is an interesting result as we can also point out that the NMAC anomaly is a special case of airborne conflict. What makes the difference between the two contexts is that another airspace, D, is also involved in our NMAC Context and one aircraft is a MLT. Thus the differences between these two contexts are small, but the anomalies are also quite similar. It will require a larger set of reports and more detailed descriptions of the Contexts (more objective parameters) to give more reliable conclusions about the differences in what happened in these two cases.

We will now focus on the differences that automated clustering reveals in the Contexts associated with Ground and Airborne anomalies. The Ground context contains the descriptor *tower*, but *neither* the *same flight phase* for the 2 aircraft, nor the *class B* airspace, nor the *parallel* runways. Thus, for these 40 reports, airborne conflicts generally entail the presence of two aircraft in the same flight phase to an airport where parallel runways are active. In contrast, Ground conflicts develop only under tower control and are not directly linked to parallel-runway configuration, just as one would expect.

7.4 An Attempt to Capture the Why

As stated previously in this report, we have introduced into the formal codification one part of the Cinq-Demi taxonomy, which captures some conditions conducive to human error. This part related to understanding the Behavior of the Scenario was not a primary aim of this small case study, but as the Cinq-Demi codification was available, it required only a little additional work to see if there were interesting results.

The study of these added parameters indicated that nearly all the conflicts were associated with a misrepresentation of risk by the air traffic controller. (The concept of misrepresentation is first introduced by Cinq-Demi as presented in Appendix B and is discussed further in Section 9 and Appendix E in this report.) Thus the behavior of the controller seemed to greatly influence the possible occurrence of a conflict.

The reports dealing with track and heading deviations seemed to be split into two clusters, depending on whether or not the flight crew had a correct representation of the trajectory of the aircraft. Thus either the behavior of the flight crew or that of the air traffic controller was a primary factor in the deviation. Moreover, for nearly all of the track and heading deviations, workload was a concern, while it seemed to be a marginal parameter in the case of conflicts.

7.5 Conclusions of the Case Study

This limited experiment showed that, within the phase of flight selected for the Context of these 40 reports, a first clustering process based on the description of the Outcome generated well-separated groups of reports. Then, the analysis of the related Contexts was able to point out discriminating parameters (e.g., active parallel runways and aircraft in the same phase of flight were related to airborne conflicts, while the transition from the TRACON control to the tower control was more relevant to track and heading deviations). Of course, with a so small a number of reports, one should be careful about the reliability and the generalization of the results. The purpose of this study was to test the value of the model, and not so much to come to conclusions about the links between Contexts and Outcomes in this small set of reports.

Moreover, the rough codification of the *why* shows that misrepresentation seems to be a common factor in all four of the anomalous outcomes of ICAC, and that some subjective parameters (for instance, workload) can be a contributing factor to some anomalies (or to some contexts). Furthermore, the indications are that the major clustering criteria for Behavior could be the person who had an anomalous behavior.

8 CORRELATIONS BETWEEN OUTCOMES AND CONTEXTS

8.1 Introduction

The Scenario model is concerned with the relationships among the Contextual factors of the last safe state, Behaviors, and anomalous Outcomes of a safety incident. We decided to examine ASRS data for evidence of such relationships.[10] In the fixed fields of the coded forms, ASRS database records contain a good deal of structured information relating to the Context and Outcomes of reported safety events, but very little structured information relating to the Behaviors of the people and automation that contributed to the events. Therefore, we limited this initial examination of ASRS

[10] This section of this research report summarizes work done by a team of researchers from Battelle Pacific Northwest Division. The team, under the leadership of Dr. Thomas Ferryman, included Ms. Amanda White, Dr. Christian Posse, and Ms. Andrea Swickard.

data to the relationship between the context of reported incidents and their outcomes, exclusively. Our intent was to extract behavioral data from ASRS narratives[11] and incorporate those data into an expanded future analysis if this initial investigation proved fruitful.

8.2 Goals

The goals of this investigation were to determine whether:

1. There are statistically significant relationships in ASRS incident reports between coded Contextual Factors, on the one hand, and coded anomalous Outcomes, on the other.
2. Any such statistical relationships that are observed in ASRS data are amenable to operational interpretation by subject-matter experts.

8.3 Approach

During this research effort we:

1. Created a structured analysis table from the ASRS data.[12]
2. Examined the statistical relationships between contextual factors and anomalies using the (a) classification and regression tree (CART) method, and (b) cross-tabulation analysis.
3. Clustered the contextual factors found in the ASRS data into groups based (roughly) on their frequency/infrequency of co-occurrence. These groups can be thought of as recurring *Contextual Patterns*.
4. Examined the statistical relationships between Contextual Patterns and anomalous Outcomes using cross-tabulation analysis.
5. Developed graphical depictions of the results of both CART and cross-tabulation analyses to aid their interpretation.
6. Presented the findings to subject-matter experts (SMEs) to determine whether the patterns revealed by the statistical analyses were operationally plausible.

This section of the current report summarizes the approach and findings of that investigation.

8.3.1 Data/Taxonomies

Data for this research were obtained from the ASRS database. The active ASRS database contained 109,225 records within the scope at the time the data request was made.

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[11] ASRS report narratives are a rich source of information regarding the behaviors of pilots, air traffic controllers, other persons, and automated agents during the course of safety events. However, the unstructured nature of these data creates an analytical challenge.

[12] Each row in the table corresponded to a reported ASRS incident. Columns described the contextual factors present during the reported event and an anomalous outcome that resulted. Since any given ASRS report may describe more than one anomaly, some reported events appear more than once in the analysis table.

Scope of Database
The scope of the analysis was limited to ASRS incidents involving at least one air transport on a passenger or freight mission flying under Part 121 rules.

Contextual Factors
As noted previously in Section 4 and Appendix C, many contextual factors relevant to safety incidents are encoded in ASRS fixed fields. The coded Contextual Factors used in this study fall into the following categories:

- **Time** including year, month, day of week, and quarter of day
- **Place** including altitude, location (airport, intersection, etc.) and involved ATC facilities
- **Physical environment** including flight conditions (VMC/IMC), ceiling, visibility, and light conditions (dawn, day, dusk, night)
- **Aircraft characteristics** including make-model (implicitly, weight, number of engines, etc.), mission, navigational-method-in-use, and flight phase
- **Hazardous situational factors** including problematic airport configurations, airspace designs, departure/approach procedures, navigational aid configurations, and ATC/airport procedures.

We used 257 ASRS contextual factor codes that fall into the above categories.[13] This set of fixed fields was supplemented with 267 context-related words extracted from the report narratives. CART analysis can accommodate large numbers of potential explanatory variables. However, cross-tabulation analyses lose statistical significance when cell sizes become too small. Thus, for the purposes of the cross-tabulation analysis, it was necessary to cluster ASRS contextual factors into Contextual Patterns (groups of Contextual Factors evidenced by very frequent or very infrequent co-occurrence).

We arrived at these contextual patterns using standard clustering methods. The raw data evidenced 2,882 distinct Contextual Factor sets (excluding location identifiers). A hierarchical clustering method was used to group these into ten Contextual Patterns. These are broadly described in table 8-1. Each ASRS report was associated with one of these ten Contextual Patterns based on its proximity to Pattern centroids.

[13] We did not treat individual locations as distinct contextual factors. If we had, the number of such factors would have been measured in the thousands.

TABLE 8-1. KEY CHARACTERISTICS OF THE 10 DOMINANT CONTEXTUAL PATTERNS OBSERVED IN THE ASRS DATA SET

Pattern	Contextual Factors Unusually Present in Pattern Members	Contextual Factors Rarely Present in Pattern Members
1	Climb phase	Thunderstorm; military/small aircraft
2	Adverse weather	Military aircraft, special purpose aircraft, ultralights;
3	Military aircraft, special-purpose aircraft, ultralights; adverse weather	
4	Descent phase	Small aircraft; adverse weather
5	Military fighters and trainers; mid-size transports	Adverse weather (except thunderstorms)
6	Ground phase	Adverse weather
7	Precipitation and obscuration factors; military aircraft	Cruise phase
8		Military aircraft; adverse weather factors
9	Landing phase	Military aircraft, special purpose-aircraft, ultralights; adverse weather
10	Military aircraft, special-purpose aircraft, ultralights	Adverse weather

Outcome Categories

We selected ten anomalous Outcome categories from among the anomalies defined in Appendix D for our analysis. These categories were selected by subject-matter experts. The chosen Outcomes were easily mapped to ASRS database codes. Table 8-2 shows the chosen Outcomes and the corresponding ASRS Anomaly codes. Any given aviation safety incident may involve more than one adverse Outcome. For example, many ASRS incident reports that involve Outcomes 1 through 8 (or 10) also fall under Outcome 9, Non-Adherence to Rules. Thus, some reported incidents appear more than once in the analysis data set.

TABLE 8-2. ANOMALOUS OUTCOME CATEGORIES USED IN THE STUDY[14]

Outcome Category		Relevant ASRS Anomaly Codes	# of Reports
Set	Label		
1	Aircraft Equipment Problems	Aircraft_Equipment_Problem.Critical Aircraft_Equipment_Problem.Less_Severe	21,802
2	Altitude Deviation	Altitude_Deviation.Overshoot Altitude_Deviation.Undershoot	8,018
3	Airborne Conflict	Conflict.Airborne_Critical Conflict.Airborne_Less_Severe Conflict.NMAC	14,427
4	Ground Conflict	Conflict.Ground_Critical Conflict.Ground_Less_Severe	4,637
5	Runway Incursions[15]*	Incursion.Runway.Other	4,201
6	Landings without Clearance	Incursion.Landing_Without_Clearance	1,057
7	Inflight Weather Encounters	Inflight_Encounter.Weather	4,472
8	Maintenance Problems	Maintenance_Problem.Improper_Documentation Maintenance_Problem.Improper_Maintenance	2,371
9	Non Adherence to Rules	Non_Adherence.Clearance Non_Adherence.FAR Non_Adherence.Published_Procedure	47,748
10	Airspace Violations	Airspace_Violation.Entry	490

8.4 Results

8.4.1 *CART Analyses*

Three Classification And Regression Tree (CART) analyses were performed. These analyses differed with respect to the contextual factors that were used as explanatory variables as follows:

Analysis 1: Used 257 contextual factors drawn from ASRS fixed fields

Analysis 2: Used a reduced set of 84 contextual factors drawn from ASRS fixed fields

Analysis 3: Used 267 context-related words drawn from the ASRS report narratives.

Analyses 1 and 2, which relied on ASRS fixed fields as the source of contextual information, seemed to produce the best results. One plausible explanation is that the coding in ASRS fixed fields, which draws on all information in the ASRS reporting form, is more consistent than contextual references in report narratives. Table 8-3 provides summary output for Analysis 2 which yielded the most useful CART results.

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14 There were 109,225 reports in total in the ASRS data set from which these observations were drawn.

15 The ASRS defines a runway incursion to include any use of a runway that is not authorized by ATC. Thus, ASRS Anomaly Code "Incursion.Runway.Other" would be more properly labeled "Runway Incursions Other Than Landings Without Clearance." Landings without clearance were separately categorized for the instant analysis as Outcome Category Set 6.

TABLE 8-3. CART ANALYSIS RESULTS SHOWING CONNECTIONS AMONG 84 CONTEXTUAL FACTORS CODED IN ASRS FIXED-FIELDS AND ANOMALOUS OUTCOMES

Outcome Category		Contextual Factors with the Most Statistical Explanatory Power
Set	Label	
1	Aircraft Equipment Problems	Mission is passenger, flight phase is climbout~intermediate altitude, climbout~takeoff, other~emergency, other~divert, cruise~level, cruise~other, ground~preflight or ground~parked, may involve a low-wing aircraft or widebody transport, mission is passenger
2	Altitude Deviation	Flight phase is climbout~intermediate altitude or descent~other or descent~intermediate altitude
3	Airborne Conflict	Two or more crews involved, flight phase is cruise~level, cruise~other, climbout~initial, climbout~takeoff, descent~approach, two or more aircraft involved, low-wing aircraft
4	Ground Conflict	Two or more crews involved and flight phase is ground~other, ground~holding, ground~preflight, ground~taxi, ground~parked, climbout~takeoff, landing~roll or landing~other, aircraft may be widebody or medium large transport
5	Runway Incursions (other)[16] *	Two or more crews involved, flight phase is ground~other, ground~taxi, ground~hold, ground~position and hold
6	Landings without Clearance	Flight phase is landing~other, landing~roll or descent~approach, may involve 2 or more crews
7	Inflight Weather Encounters	Flight phase is cruise~other, descent~approach, descent~other or landing~other, may involve high-wing aircraft or 2 or more crews
8	Maintenance Problems	Flight phase is ground~maintenance, ground~parked or cruise~level, may involve low-wing aircraft
9	Non Adherence to Rules	No positive evidence
10	Airspace Violations	Flight phase is cruise~level, may involve low-wing aircraft

8.4.2 Cross-Tabulation Analysis

We cross-tabulated the data set using the ten identified Contextual Patterns as the rows and ten chosen anomalous Outcomes as the columns. We then computed the ratio between the observed number of observations in each cell and the statistically expected number of observations. Figure 9 shows the results. It is color-coded to highlight ratios that are unexpectedly high and those that are unexpectedly low.

[16] The ASRS defines a runway incursion to include any use of a runway that is not authorized by ATC. Under this definition, an unauthorized landing is a type of runway incursion. Thus, Outcome Category 5, Runway Incursions. Others should be understood to mean "runway incursions other than landings without clearance." Landings without clearance were separately categorized as Outcome 6 for the purposes of this study.

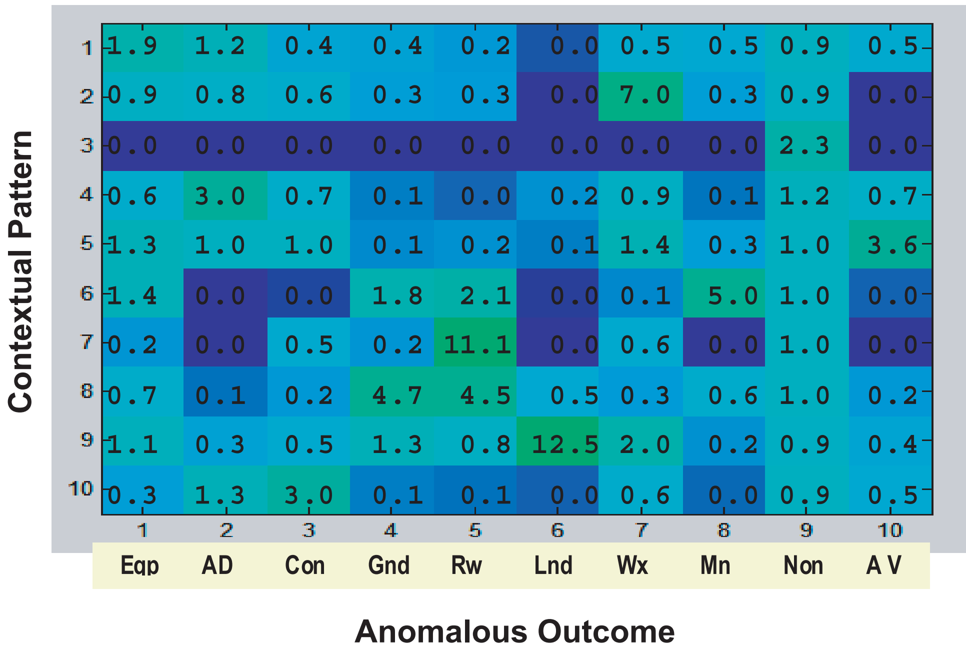

Figure 8. Cross-tabulation results showing ratio of observed over expected cell frequencies.

Figure 8 clearly reveals strong statistical relationships between the Contextual Patterns and anomalous Outcomes described in ASRS incident reports. For example, Context 2 (roughly, adverse weather) is negatively correlated with Outcome 6 (landings without ATC clearance). This is consistent with prior ASRS research that suggested that most landings without clearance occur in VMC conditions. Favorable weather can contribute to flight crew complacency and associated errors of omission. Context 10 (roughly, the presence of military or special purpose aircraft in adverse weather) appears to significantly increase the statistical likelihood of Outcome 3 (airborne conflicts). Subject matter experts agree that airborne conflicts are more likely to arise when aircraft with very different performance characteristics (e.g., air transports, military aircraft, or special-purpose aircraft) are in the same traffic mix. This potential is heightened in marginal weather conditions. Similar interpretations can be made of a number of other statistical relationships observed in the cross-tabulation results.

8.5 Lessons Learned

While far from definitive, the research described in this chapter yielded some important lessons. First, we are encouraged to believe that relationships that are both statistically and operationally meaningful exist between Contextual Factors/Patterns, on the one hand, and specific types of unwanted aviation safety Outcomes, on the other. Second, we recognize that the multiplicity of contextual factors that may be present during aviation safety events creates analytical challenges (i.e., the dimensionality needs to be reduced through recurrent pattern identification). Third, we recognize the danger that studies such as these can produce analytical results that are tautologies (things true by definition) rather than true insights. This happens when an Outcome has contextual factors built into its definition (e.g., landings without clearance, by definition, occur during the landing phase). Fourth, we better understand the importance of bringing domain expertise into the research process at the beginning of the research study rather than reserving its application to the interpretation of research results at the end. Domain expertise can be used to achieve dimensionality reduction based on operational rather than mathematical considerations, identify implicit tautologies, and otherwise assist study design and execution.

9 ON THE CODIFICATION OF THE WHY

We now come to the primary purpose of this study.

In Section 5, we described our concept of the Scenario,

SCENARIO = {CONTEXT + BEHAVIOR ➔ OUTCOME}

in which we consider the Context to be that of the last safe state and the Behavior results in the transition to the Outcome. When the Outcome is an anomalous (unwanted or compromised) state, the last safe state is identified as a precursor.

In the experiment discussed in Section 8, we clustered incidents on the basis of similar patterns of parametric values defining their Contexts and their Outcomes. We have adequately described *what* happened, but we have not yet identified the causal factors of the Behavior that produced the transition from the last safe state to the unwanted Outcome – the *why*. For this, we must rely on a second stage of clustering. We will use the results of clustering on *what* combined with domain knowledge to minimize the extent of the world that the automated tools must consider in this second stage of clustering.

In order to answer the most important human-factors questions about an incident, we must extract causal information from the free narrative of the incident report. We need not do a perfect job of this. The identification of *what* happened in the first stage of clustering already achieves much of what is needed for an effective retrospective search. Furthermore, our aim is not a definitive explanation of why a given incident occurred. We cannot expect to automate a completely reliable understanding of the *why*. We only need the capability to expedite a search on the *why,* to enable an exploration of their commonalities, and to minimize the labor of the human expert in arriving at a satisfactory explanation. It is sufficient to restrict the space of possible causal factors, and, in some cases, to identify a set of related incidents that includes almost all those that would be selected by an expert as similar to the target incident.

It is fortunate that we do not have to be perfect in automatically extracting the precise *why* events happened, because this study is based solely on ASRS incident reports. As products of a voluntary reporting system, the reports in the database have some inherent limitations. They cannot be viewed as a random sample of the population of aviation incidents, they may contain reporting biases, and their factual correctness cannot be verified. Moreover, retrospective experiential reports like the ASRS reports are not reliable reports about why incidents happened. Ericsson and Simon (1993) have reviewed and analyzed many decades' worth of research on the uses of verbal reports. They repeatedly emphasize two points, both of which are relevant and of concern to our experiment based on aviation incident reports:

- People have no ability to verbalize their own perceptual and cognitive processes. But it is precisely the understanding of the perceptual and cognitive processes that is fundamental to identifying the causal factors of the Behavior.
- People have little or no ability to provide any accurate information about their performance or cognition after a short time has passed. However, ASRS reports are usually provided several hours after the target events.

Furthermore, people cannot report on the perceptual and retrieval processes that determine which thoughts or patterns reached their attention or why a given thought was attended. Perhaps the best we can hope for is a sequentially correct report of the most salient attended objects and events, especially those attended during impasses in normal, smooth performance. For the most part, the reported events will relate to the *what*, but when they are related to *why*, they are almost certain to be directly linked to concrete perceptual factors. While this source of our information about the *why* may be flawed, it is nevertheless the best source we have for the operator's perspective of the incident, and it deserves to be mined for whatever information it contains.

In this second stage of automated analysis, we need to rely on knowledge of human behavior to narrow the possibilities of the *why* in order to "aim" the automated system in the proper direction. In fact, at this stage of the research, we are willing to omit many plausible (albeit rare) causal factors of human behavior (such as physiological and psychomotor factors) if we can aid the analyst in the identification of a few important common ones. In our initial attempt to cope with this complex problem, we propose that the Behavior entailed in transitioning from the safe state to a compromised or anomalous state of the Outcome is always associated with a loss of "Situation Awareness."

Endsley (1988) defines Situation Awareness (SA) as a person's *"perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."* SA is a label that is often used to refer to many of the cognitive processes entailed in attentional dynamics, maintenance of a world model, and prediction. This definition fits well with our view of Behavior as we use it in the concept of Scenario. Moreover, the concept of associating any Behavior that results in an anomalous Outcome with a failure of Situation Awareness fits with our objective of identifying systemic factors conducive to human error. SA is concerned with the operational state of an expert human performer in a dynamic and potentially dangerous environment. In our aviation world, we are considering pilots and air-traffic controllers operating in the global civil aviation environment. Other studies of SA have focused on challenging military operations, such as command and control in joint-operations combat. Still others have studied automobile drivers, anesthesiologists, space mission ground-controllers, and firefighters. We base our approach on the substantial body of literature reporting on a variety of perspectives of SA and its role in human behavior. (See, for example, Durso and Gronlund 1999, Shively et al. 1997, and Sohn and Doane 2000.)

SA is the converse of the concept of Misrepresentation that is an "Error Factor" in Cinq-Demi's GOOF grid. (See Appendix B.) Cinq-Demi uses Misrepresentation to mean situations when the model used by the operator to understand events and act accordingly is, for any reason, not consistent with the "real world." Misrepresentation involves the reporter's failure to update his or her mental model of system status; it can also involve use of a decision model that may be generally valid, but is too simple, or is inappropriate to the reported situation. Misrepresentation is viewed here as synonymous with loss of Situation Awareness.

This notion—that the loss of SA (or Misrepresentation) always underlies the Behavior associated with the transition from a safe state to a compromised or anomalous state—has some justification, at least with regard to ASRS reports. In every study we have conducted in which the full analyses using the Cinq-Demi methodology have been applied to ASRS reports, we have concluded that Misrepresentation dominated all of the Error Factors. Further, experienced ASRS analysts agree that "Misrepresentation" (in its most general interpretation) is the dominant factor in, by far, the majority of the ASRS reports in the database, except in some cases of equipment failure.

Hartel et al. (1991) found SA to be the leading causal factor in a review of 175 military aviation mishaps. Endsley (1995a) investigated the causal factors underlying aircraft accidents involving major air carriers from 1989 to 1992. Of 24 accidents, 17 involved human error and, of these, 15 were associated with a failure of Situation Awareness. Endsley concluded, *"This study provides good evidence that problems with Situation Awareness are indeed a primary factor underlying aviation accidents."* This conclusion was further validated by the results of the studies reported in Jones and Endsley (1996) and Gibson et al. (1997), although these entailed only small subsets of incident reports from the ASRS database.

Therefore, it may not be too extreme to start with the assumption that the human behavior failures of every incident entail loss of Situation Awareness, especially as the ASRS database will be our resource for experiments. This provides us with a model to guide the automated clustering. Moreover, the automated clustering processes to be used in this experiment lend themselves to testing this assumed model, as will be described later.

However, SA by itself is non-constructive and insufficiently discriminating. To make progress with the analysis and measurement of our conceptual model, it is necessary to break SA down into more concrete and constructive components. Fortunately, we can draw on an extensive SA research literature to accomplish this. (See Appendix E for a discussion of this literature and research in related domains of human factors, skilled performance, and behavioral decision theory. Appendix E also discusses some of the complex processes and interactions that we are ignoring in this initial experiment.)

The human-factors research community (see, for example, Endsley 2000a, Endsley 2000b, and Shively, R. J., et al. 1997) has identified the following sequential stages or aspects of Situation Awareness:

SITUATION AWARENESS

DETECTION
↓
RECOGNITION
↓
INTERPRETATION
↓
COMPREHENSION
↓
PREDICTION

We propose that the discriminating factors of Behavior in our model of Scenario are failures to Detect, Recognize, Interpret, Comprehend, or Predict. (See Appendix E for descriptions of each of these five components of SA.)

There are three benefits to our experiment that can be realized by adopting this breakdown of Situation Awareness. First, the determinants are constructive in the sense that each might be identifiable with specific words or phrases in a set of reports. Second, they are constructive in the sense that we may be able to relate each to specific objective parameters of the Contexts and Outcomes of each Scenario. Third, as they are naturally sequential, they have the potential for augmenting the information on the sequence of events (or sub-events) during the transition from the last safe state to the outcome. All of these features can be useful to "tuning" the automated analyses of this second stage, as will be described later.

A number of previous studies have highlighted levels or stages of SA that are closely related to our list of discriminating components: Detection, Recognition, Interpretation, Comprehension, and Prediction (DRICP). For example, Endsley developed the taxonomy in table 9-1 for classifying and describing errors in SA (Endsley 1994, 1995a, and 1995b). The factors affecting SA at each of the three levels of table 9-1 correspond to the components of SA we propose to use. Detection and Recognition are necessary for Level 1 SA (Endsley 1996, 2000a, and 2000b). Interpretation and Comprehension are necessary for Level 2 SA (Endsley 1996, 2000a, and 2000b). A person with Level 2 SA has been able to derive operationally relevant meaning and significance from the Level 1 data perceived. Endsley 2000a and 2000b emphasizes that the defining role of prediction is the highest level (Level 3) of SA. We may well find that it is not possible to discriminate automatically to the five levels of detail of our taxonomy, in which case we will try to adapt our analyses to Endsley's three-level taxonomy of perception, comprehension, and projection. In any case, Endsley's lower-level descriptions of each of the three levels in table 9-1 will help us develop representative concepts, words, or phrases that a reporter of an incident might use to indicate the components of SA.

Jones and Endsley (1996) found that experts achieved a limited degree of success in categorizing a small sub-set of ASRS reports at these three levels of table 9-1. They also found that the distribution of errors among the three SA Levels in the 143 ASRS incident reports of this study was comparable to that found in a previous study of 17 NTSB accident reports (Endsley 1995b).

TABLE 9-1. TAXONOMY OF LEVELS OF SITUATION AWARENESS

Level 1: Fail to perceive information or misperception of information • Data not available • Hard to discriminate or detect data • Failure to monitor or observe data • Misperception of data • Memory loss Level 2: Improper integration or comprehension of information • Lack of or incomplete mental model • Use of incorrect mental model • Over-reliance on default values • Other Level 3: Incorrect projection of future actions of the system • Lack of or incomplete mental model • Over-projection of current trends • Other

With this assumed model of Behavior, we now have a taxonomy of sequential, constructive, discriminating factors of Behavior that could help explain the *why* and *how* of an incident. We next need to identify which of these behavioral factors (i.e., failure to Detect, Recognize, Interpret, Comprehend, or Predict) were present in the Scenario of the subset of incident reports developed from the first stage of clustering on *what* happened. Then we need to identify the objective factors of the Context that are related to the identified behavioral factors.

Accordingly, in order to maximize the potential of the automated extraction of this information, we expect to do the following in the experiments that we will conduct during the next year: (This corresponds to the second stage of clustering in the procedure diagrammed in figure 9.):

1. An expert in human factors will work with operational experts (ASRS analysts) to develop representative concepts, words, or phrases that a reporter of an incident might use to indicate the components of SA (DRICP). Examples are presented in table 9-2.
2. We will then use such exemplary phrases with the tool called QUORUM-Perilog (McGreevy and Statler 1998) to search the entire ASRS database for similar phrases. On the basis of that search, we will develop a set of words, phrases, and phraseologies related to each of the discriminating components, DRICP, of SA.
3. With the help of operational domain experts and experts in human factors, we will develop subsets of the previously labeled subjective factors that relate to each of the components of SA. We will then use the set of phrases developed in step 2 above, together with the subset of subjective factors associated with each of the discriminating components of SA, to “tune” the automated analysis in the second stage of clustering. This second stage will cluster reports by similarity of the failures in SA (i.e., failure to detect and/or to recognize and/or to identify, etc.) that occurred from each cluster of incident reports identified in the first stage of analysis as similar on the basis of what happened.

TABLE 9-2. REPRESENTATIVE TEXTUAL EXPRESSIONS

	Concepts	Words	Phrases
Lack of Detection	threshold, change, adaptation level, signal quality, discrimination, noise	did not notice, see, hear, monitor	I did not notice that the MCW light was on. We were not monitoring altitude.
Lack of Recognition	attention, familiarity, type/kind/category, importance	misunderstood, misread, mis-heard, confused, unknown, novel, new, unfamiliar	An unfamiliar annunciation appeared on the MCP. PNF mis-heard the clearance.
Lack of Interpretation	relations, reasoning, language, training, specialized knowledge	incorrectly, not fully, incompletely; not realize meaning, importance	CAPT did not realize how soon we needed to start the descent.
Lack of Comprehension	causality, explanation, diagnosis, intervention, FDIR	lost track of, mistake, wrong, error, why, misunderstand	We did not understand why the altitude capture failed. (notice in this case how detection, recognition, and interpretation are satisfied: 'the altitude capture failed' is an interpretation of cockpit information that has been detected and recognized; still there can be a comprehension failure)
Lack of Prediction	prediction, preparation, expectation, prevention, avoidance	not expect, unexpected, unforeseen, not remember to	The weather had deteriorated at our alternate. We got an unexpected runway change.

4. Again, an expert in human factors will work with ASRS analysts to identify which of the objective parameters of the Context might relate to a failure of each of the discriminating components of SA (i.e., which of the objective parameters might contribute to a failure to Detect, which to a failure to Recognize, which to a failure to Interpret, which to a failure to Comprehend, and which to a failure to Predict). This step is intended to guide the automated search of the next step.

5. The automated analysis in Step 3 identifies which of the components of SA pertain to the Behavior of the common Scenario in a cluster of incident reports. Next we will automatically compare the objective parameters of the Context for that Scenario with the list of those parameters that the experts identified as relevant to each of the pertinent components of SA. This comparison will enable us to identify the subset of objective parameters of the Context that is related to each of the discriminating factors of the Behavior identified with that Scenario.

6. After identifying which of the components of SA are entailed in the Scenario, it might be possible to extract some information about the chronology (linkage) of the sub-events from the natural sequence of the components of SA by relating these to their corresponding existing contextual factors. The consequent completion of the Scenario that includes this chronology of the contextual factors and their relationship to the components of SA permits the postulation of effective intervention.

We use the DRICP framework as though Detection, Recognition, Interpretation, Comprehension, and Prediction occur in sequential order, each successive stage using the output of the preceding stage. This simplification is both necessary and justifiable in the initial part of our work. It is necessary to keep the analysis tractable, and it is justifiable because there is every reason to believe that ASRS reports are usually delivered as sequential narratives.

However, as Carroll et al. (2001) documents, citing Neisser (1976), human cognition is a cyclic process in which prediction facilitates comprehension and interpretation, and in which comprehensible and interpretable events are more easily detected and recognized than are unpredictable and incomprehensible events. In fact, Jones and Endsley (1996) point out that many Level 2 SA errors (for example, misinterpretation of landmarks) can be attributed to incorrect expectations (erroneous predictions), which then cause a persistent misrecognition and misinterpretation of perceptual data.

During the next year, we expect to conduct the experiment described above, applying the paradigm of Situational Awareness to automated clustering on the parameters extracted from ASRS incident reports associated with erroneous human Behavior. We will present the results of this experiment in a subsequent report.

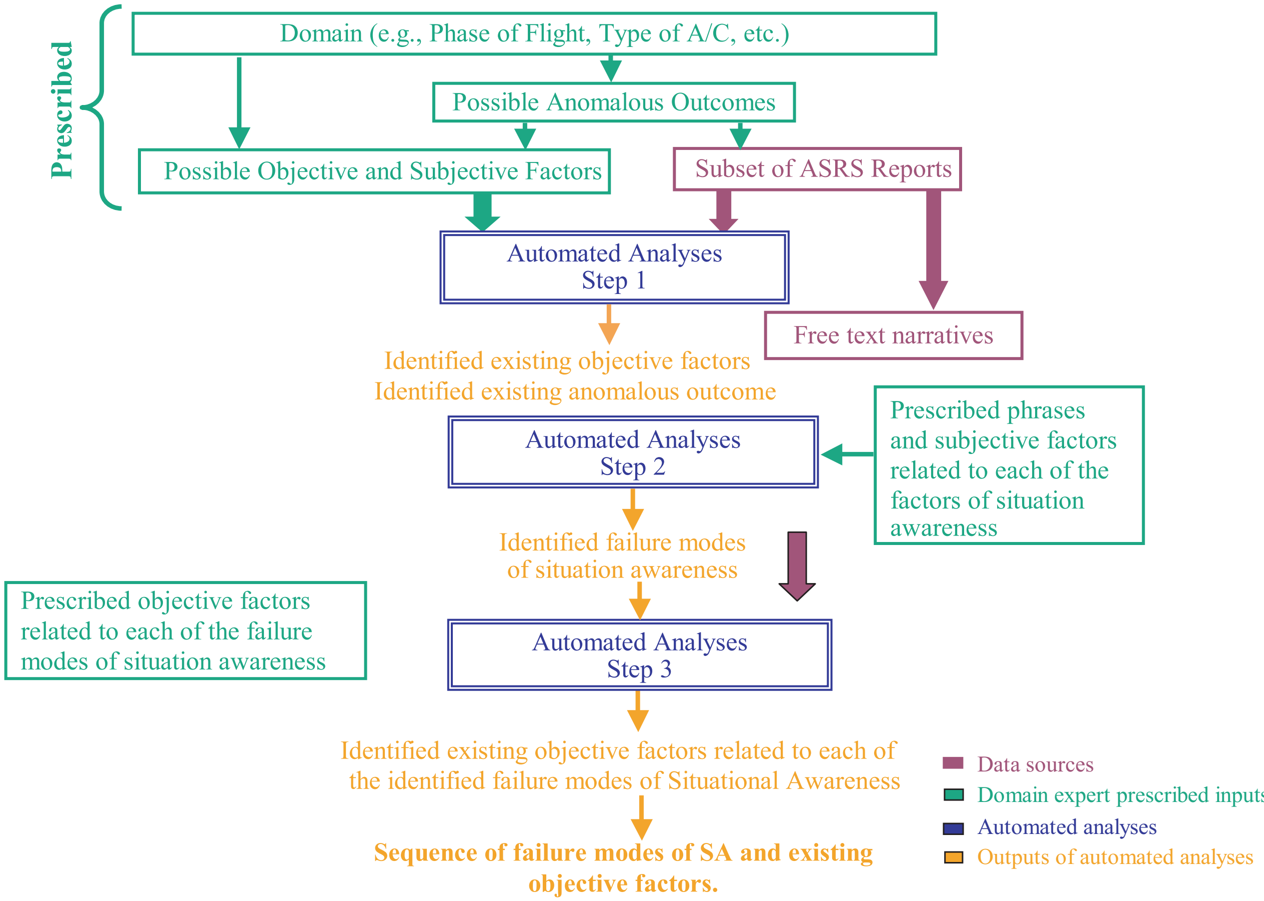

Figure 9. Process for second-stage analysis.

10 SUMMARY AND PROJECTIONS

In this study, we have defined a generic structure of information (a taxonomic model) that is postulated to be a sound basis for defining similarities between incidents like those described in ASRS-like aviation incident reports. On the basis of this structure, we have introduced the simplifying structure of the Scenario as a pragmatic guide for identifying similarities of what happened based on the objective parameters that define the Context and the Outcome of a Scenario.

We assume that it is possible to design an automated clustering process guided by the structure of the Scenario, and that the results will be easy for human experts to understand. We have identified the “full and complete” set of parameters that define the Context of the initial safe state, and the anomalous Outcome. Our assumption is that this complete set of parameters adequately describes what happened. Automated tools will use the values of these parameters to identify the Scenario and to cluster similar scenarios from the ASRS database based on what happened. We have demonstrated the potential of this approach in the experiments described in this report.

The limited experiment of the “Case Study” discussed in Section 7 showed, within the limitations of the small number of reports used, the value of the Scenario model for clustering reports based on similarities of Context plus Outcome. Moreover, the rough codification of the *why* for this small set of reports showed that misrepresentation was a common factor and identified some subjective parameters that can be contributing factors to Behavior. This experiment encouraged us to continue with our approach to analyzing free text for information on why an incident occurred.

Then we used our current automated capabilities to cluster the objective parameters as they are coded in the current ASRS database. We considered the dominant cluster to be representative of the Context of each Scenario, and determined that there are certain common dominant factors associated with each anomalous Outcome. We cross-tabulated the data set using ten identified Contextual Patterns as the rows and ten chosen anomalous Outcomes as the columns. We then computed the ratio between the observed number of observations in each cell and the statistically expected number of observations. We concluded that relationships that are both statistically and operationally meaningful exist between Contextual Factors/Patterns, on the one hand, and specific types of unwanted aviation safety Outcomes, on the other. We recognized that the multiplicity of contextual factors that may be present during aviation safety events creates analytical challenges (i.e., the dimensionality needs to be reduced through recurrent pattern identification).

This report has presented a first-generation process for routinely searching large databases of aviation accident or incident reports, and consistently and reliably analyzing them for objective factors (the *what* of an incident) as well as the causal factors of human behavior (the *why* of an incident). We have proposed a method for applying the paradigm of Situational Awareness—with its five components of Detection, Recognition, Interpretation, Comprehension, and Prediction—to automated clustering on the objective and subjective parameters associated with erroneous human Behavior from the free-text narrative of an incident report. Noting that the discriminating components of SA have a natural sequence, or chronology that can be linked with event chains, we have postulated the possibility of identifying effective interventions for the elements of human error identified in incident and accident data.

We have assumed a very simple model for describing the human behavior associated with the transition to an anomalous state in our concept of the Scenario. There are likely other factors besides loss of SA that could influence transitions in some scenarios. However, the research literature documents the very high frequency with which human error can be related to loss of SA. Certainly, not all of the contextual factors of the last safe state prevail unchanged throughout the transition, and those changes both influence and are influenced by the human actions on the system. Also, it is clear that human cognition is a cyclic process and not the simple sequential process of our DRICP framework. Nevertheless, we maintain that our simplified model of Scenario and Behavior is both necessary and justifiable in this first generation of automated analyses of free text. It is necessary to keep the analysis tractable within currently available capabilities, and it is justifiable because there is every reason to believe that ASRS reports are usually delivered as sequential narratives. The research process will be designed to continuously question our assumptions, and our simplifications will be corrected as required through future investigations.

The plan is to continue to develop and enhance the automated capability to correlate Context and Outcome by incorporating additional domain knowledge. For this first-generation process, we believe that it is essential to (1) maximize the information from the objective parameters about what happened in order to minimize the domain for analyzing why it happened, and (2) assume a simplified model of Behavior to begin to analyze automatically for an understanding of why. In the experiment to be conducted during the next year, we will evaluate the ability to automatically extract useful information about why a set of similar incidents occurred based on this simplified model.

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APPENDIX A: CURRENT TOOLS

Several commercially available tools have been evaluated in queries of the ASRS database:

BRIO: Enables the performance of a Boolean search (SQL-like) on the relational database containing the codified part of the incident. Moreover, it enables a search for words in the free-text section. This tool is efficient and widely used for retrospective searches. The user must know how to formulate a “good” question in order to use BRIO effectively.

QUORUM: QUORUM-Perilog is a set of methods and software for data mining of text and other sequences of symbols. QUORUM measures the degree of contextual association of large numbers of word pairs in narratives and other text to produce models that capture the contextual structure of the text. It compares models to measure their degree of similarity. The QUORUM tool is primarily dedicated to retrospective searches, rather than analyses.

Vivísimo Clustering Engine™: Interfaces with any document database to automatically organize search or database query results into hierarchical folders of categories that are selected from the words and phrases contained in the search results themselves. In a small experiment on a subset of ASRS reports, Vivísimo was found to be easy to run and was able to identify operationally pertinent concepts and exemplars. However, it was more effective when used on categorical fields than on free text, and the preprocessing of vocabulary was an important enabling step.

Battelle PNWD methodology: A new set of tools has been developed in order to mine the ASRS database and build clusters without knowing what we are looking for. This methodology uses domain knowledge to standardize the language of the free text for processing (an automated filtering process called PLADS), statistical tools to identify clusters and super clusters (Matlab), and a software dedicated to navigating the hierarchical structure (called ALAN). The AUTOMATIC LANGUAGE ANALYSIS NAVIGATOR (ALAN) is a text comprehension tool that clusters textual data. ALAN identifies aviation safety reports that have similar topics, or identifies clusters of reports that are similar to a given exemplar (Willse et al. 2002).

The heart of the ALAN methodology relies on the extraction of a signature for each report. The signature and the definition of the similarity between two signatures are based on word counting in the free text. Results of clustering are often difficult to understand from an operational perspective, they do not provide automated identification of precursors, and they cannot be used to build an intervention strategy for a critical situation. Research is currently being conducted to make better use of domain knowledge to improve the efficiency and the operational relevance of the clustering tools.

APPENDIX B: THE CINQ-DEMI METHODOLOGY

During the 1980s, a French organization called Cinq-Demi developed a tool for analyzing conditions and the operational system faults underlying incidents or accidents (Lecomte et al. 1992, Wanner 1999).[17] This methodology has been used successfully to analyze accidents in a variety of domains, and on selected accident-inducing events reproduced in a flight simulator. In 1992, personnel of NASA-FAA's Aviation Safety Reporting System (ASRS) Office became interested in evaluating the potential application of this method to the ASRS database to aid identification of aviation system deficiencies. Representatives of the ASRS initiated discussions with ONERA and with Cinq-Demi about collaborating on an evaluation of the methodology.

In 1995, NASA and ONERA agreed to a new task titled "Human Factors in Aeronautical Operations and Incidents" under the existing ONERA-NASA Memorandum of Agreement (MOA) for collaborative research in aeronautics. The intent of this task was to evaluate the applicability of the Cinq-Demi methodology to the ASRS incident database. Consequently, the Cinq-Demi method was tested and was found to agree closely with the opinion of ASRS analysts in identifying incident causal factors in a sample set of about 300 ASRS reports.

The underlying concept of the Cinq-Demi methodology is best understood from the perception of aviation safety depicted in figure B-1. The status space of figure B-1 is an N-dimensional space representing all the parameters that define the state of the system. The "Status Point" defines the state of the world from the perspective of the aircraft. The operational objective is to maintain the Status Point within the "Authorized Flight Envelope" where the probability of an accident is very low (say, 10^{-7}). Outside the Authorized Flight Envelope is the "Peripheral Envelope" where the probability of an accident is somewhat higher (say, 10^{-3}). A trespass into the Peripheral Envelope is an *incident*. In such cases, the task of the operator is to bring the aircraft back from the Peripheral Envelope to the Authorized Envelope. When the trespass exceeds the Peripheral Envelope, the consequence is a *highly probable accident*.

[17] There are substantial similarities between the Cinq-Demi methodology and the Human Factors Analysis and Classification System (HFACS) (Shappell and Wiegmann 1997, Wiegman and Shappell 2001) that has become well known in the US.

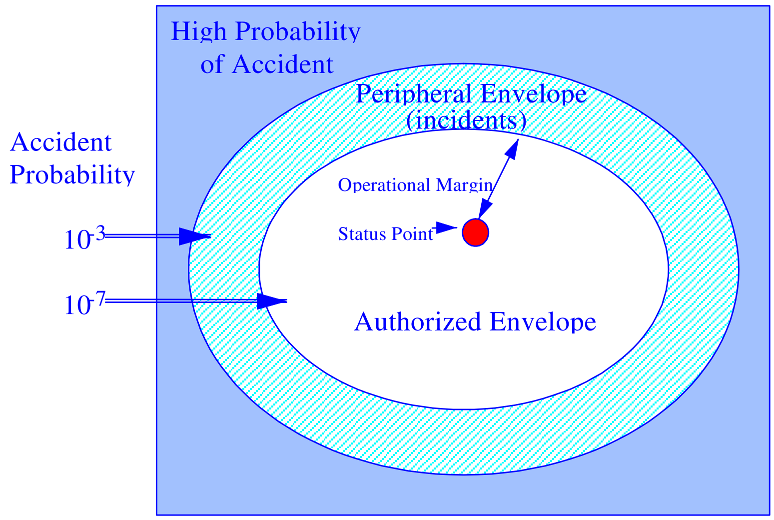

Figure B-1. A view on accident prevention.

There are only three types of activities that can influence the movement of the Status Point, and these are represented in the first three grids of Cinq-Demi's structured methodology for analysis. One such type of activity is associated with "Maneuverability," represented in a Cinq-Demi coding grid called the "Grid of Aircraft Maneuver Events (GAME)" (fig. B-2). The GAME grid lists the maneuvers that are either imposed by the mission, or required for correction of the Status Point to accommodate environmental events.

MANEUVERABILITY	
Maneuvers imposed by the mission	
Speed or Mach Number changes	Mmm
Flightpath angle changes (particularly flare)	Mmp
Heading changes (turn entry, turn, turn exit)	Mmc
Altitudes changes (climb or descent entry, climb or descent, level off)	Mmh
Configuration changes (Landing gear, flaps, airbrakes, systems on/off)	Mms
Correction maneuvers	
Speed or Mach Number correction	Mcm
Angle of attack or Longitudinal Attitude correction	Mci
Sideslip angle correction	Mcd
Lateral Attitude correction	Mca
Heading correction	Mcc
Altitude correction	Mch

Figure B-2. Grid of aircraft maneuver events (GAME).

The second type of activity is "Sensitivity to Disturbances," represented by the "Grid of Aircraft Sensitivity to Perturbations (GASP)." (See fig. B-3.) The GASP lists perturbation events that are due to internal disturbances (such as a system failure), or external disturbances (such as turbulence or a sudden change of runway status) that result in movement of the Status Point.

SENSITIVITY TO PERTURBATIONS	
External Disturbances	
Gust	Sraf
Wind Gradient	Sgrv
Turbulence	Stur
Thunderbolt	Sfdr
Icing	Sgiv
Hail	Sgrl
Runway (Rapid change of status: holes, patches of snow…)	Spst
Bird	Soix
Internal Disturbances	
System Failure	Span
Fire	Sfeu
Cabin pressure loss	Sprs
Disturbance due to passenger	Spax

Figure B-3. Grid of aircraft sensitivity to perturbations (GASP).

The third type of activity is "Pilotability," represented by the "Grid of Operator Failures (GOOF)." (See fig. B-4.) In performing a task, an operator can miss or badly execute an elementary operation. GOOF identifies the "Elementary Operations" and the "Error Factors," i.e., the conditions leading to that error. The Elementary Operations are Data Collection, Data Treatment and Decision, Data Transmission, and Action. There are five Error Factors: High Workload, Lack of Informational Cues, Misrepresentation due to wrong use of information and cues, Misrepresentation due to "diabolic" error, and Clumsiness.

GOOF	ELEMENTARY OPERATIONS			
ERROR FACTORS	Data Collection Machine⇒Man *or* Man⇒Man *s	Decision after Data Treatment (Diagnostic) *d	Data Transmission Man⇒Machine *or* Man⇒Man *t	Action *a
High Workload C*	Saturation : Data not collected or wrongly captured. Cs	Null, partial or wrong data treatment (diag-nostic) leading to a bad decision. Too fast or too late decision. Cd	Saturation : Transmission inexistent, incomplete or wrong. Ct	Saturation : No action or erroneous action on a control. Ca
Lack of cues (Under vigilance, very low workload) A*	Lack of vigilance : Data not collected or wrongly captured. As	Null, partial or wrong data treatment (diagnostic) leading to a bad decision. Too late decision. Ad	Lack of vigilance : Transmission inexistent, incomplete or wrong. At	Lack of vigilance : No action or erroneous action on a control. Aa
Misrepresen-tation (Model error, Wrong use of Data) M*	Use of a wrong data collection model (localization, identification or transposition model). Ms	Use of a wrong working or risk model : false, oversimplified or too complex. Md	Use of a wrong transmission model (localization, identification, way of action, addressee). Mt	Use of a wrong controls model (localization, identification, way of action, status…) Ma
Misrepresen-tation (A priori model "diabolic" error) P*	Data collection limited to those which corroborate the a priori model. P	Changes of situation denied or forgotten. No risk awareness. Pd	Change of transmission status denied or forgotten. Pt	Action based on the a priori model. Pa
Clumsiness L*	Wrong data collection by visual or auditory lapse. Ls	Misunderstanding during data treatment. Ld	Wrong transmission by slip of the tongue. Lt	Erroneous action due to an incorrect motion of a hand, a foot, a finger… La

Figure B-4. Grid of operator failures (GOOF).

To describe an incident or an accident using the Cinq-Demi process, the analyst of a reported incident must first list, in chronological order, the sequence of sub-events as reported and then, for each sub-event, identify and code the three types of reported activities that can move the Status Point, by making the appropriate selections from the GAME, GASP, and GOOF grids. Cinq-Demi points out that other factors related to the operator’s physical and psycho-sociological behavior can be conducive to human error, but these cannot be resolved through operational or technical solutions. Factors such as these must be taken into account only to estimate the probability of occurrence of the same situation. They are accounted for in the fourth grid, called the “Grid of

Amplifiers of Risk of Errors (GARE).” (See fig. B-5.) The GARE grid is used to identify the human environment at the time of the incident. It includes physical factors, physiological factors, psychological factors, and sociological factors.

GARE – Grid of Amplifiers of Risk of Errors			
Physical Factors Pk	External Factors Pke	Reduced Comfort	– Seats, abnormal body position …
		Embarrassing working suit	– Safety suit, gloves, boots, spectacles, mask, earphones,…
		Work station motion	– Vibrations, shakes, low frequency oscillations (air sickness), work under load factor…
		Environment	– Temperature (High or Low), cabin pressure, humidity, lighting (too low or too high), noise, smell…
		Time at incident occurrence	– Mission beginning or end, just back from holiday or just before holiday, during holiday, schedule changes…
	Internal Factors Pki	Medicines Alcohol Drugs	
Physiological Factors Pg		Fatigue	
		Needs	– Hunger, thirst, natural needs…
		Pathological status	– Sickness, flu, aches (head, teeth, ears…), itching, incapacitation (faint, death)
Psychological Factors Ps		Fear, Anguish Personal troubles Family troubles, Memory loss, madness…	
Sociological Factors S	Internal Factors Si	Crew or team structure Crew member’s qualification Occasional manpower shortage Learner, beginner… Team internal dispute…	
	External Factors Se	Bad social environment (strike…) Visitor, Instructor, Inspector VIP… on board	

Figure B-5. Grid of amplifiers of risk of errors (GARE).

The matrix of Operational System Faults and Elementary Operations constitutes the fifth and final coding grid that is called the “Rapid Analysis Fault Table (RAFT).” (See fig. B-6.) Cinq-Demi presumes that the error factors identified in the GOOF grid have their roots in systemic faults. The RAFT grid is meant to help to analyze these system faults of an incident, and to categorize them relative to the following concepts:

- Organization (crew roles, responsibilities, tasks, and procedures)
- Design (basic design concept rather than interface)

- Design Interface-Mechanical ergonomic (interface design for operation)
- Design Interface-Mental ergonomic (interface design and interpretation)
- Education-Training Basic
- Education-Training Specific (systems, model, and proficiency)
- Documentation (physical faults)
- Documentation (wrong content)
- Requirements (company, regulatory, and equipment manufacturer)

Within the computerized version of the grids for GOOF and RAFT, there are illustrative examples and definitions available at each “cell” within these matrices (accessible by a double-click of the mouse on the cell) to aid the analyst in deciding on the appropriate categorization for an event.

RAFT		ELEMENTARY OPERATIONS			
OPERATIONAL SYSTEM FAULT		Data Collection Machine⇒Man *or* Man⇒Man *s	Data Treatment (Diagnostic) Decision *d	Data Transmission *t	Action *a
ORGANIZATION O**	ORGANIZATION Who has to do ? Responsibility	Or			
	ORGANIZATION What to do ? Carrying out	Oe			
	ORGANIZATION With what to do ? Means	Om			
	ORGANIZATION How to do ? Drills Op*	Ops	Opd	Opt	Opa
INTERFACES H**	INTERFACES Mechanical ergonomy Hm*	Hms	Hmd	Hmt	Hma
	INTERFACES "Mental" ergonomic Hc*	Hcs	Hcd	Hct	Hca
EDUCATION F**	EDUCATION-TRAINING Basic education Fb	Fb			
	EDUCATION-TRAINING Specific educ. Fs*	Fss	Fsd	Fst	Fsa
DOCUMENTA-TION D**	DOCUMENTATION Physical faults Dm	Dm			
	DOCUMENTATION Wrong content Dc*	Dcs	Dcd	Dct	Dca
	REQUIREMENTS R*	Rs	Rd	Rt	Ra

Figure B-6. Rapid analysis fault table (RAFT).

APPENDIX C: TAXONOMIC STRUCTURE FOR CODIFICATION

In the example presented in Section 3.2 (see fig. 2), states and events have been described in an informal way by sentences or words extracted from the narrative. Choosing the particular set of parameters that describe each state of the world, and the particular set of parameters that describe each transition, will give us a more formal description of each part of the Scenario of such an incident.

A wide range of taxonomic structures[18] is used in the various accident/incident databases. These structures often contain parts related to the description of the flight circumstances, and others that relate to the human factors of an event. As an example, O'Leary et al. (2002) gives a flavor of the type of parameters used in the British Airways Safety Information System (BASIS), while Murayama and Yamazaki (2002) show some of the Performance Shaping Factors used in a marine incident reporting system. The basis of our study relies on a consolidation of the three taxonomic structures that underlie three codifications[19] that were designed specifically for use with ASRS reports:

- <u>The ASRS codification</u> is a structured set of 'descriptors' that is currently used to describe the incident and store it in the database. The codification is designed for use by operational personnel. It is limited, primarily, by the size of the current paper-reporting form that the ASRS Office uses for the sake of maintaining confidentiality. After 28 years of operation, well over 100,000 ASRS incident reports have been codified with this taxonomic structure and are available in the ASRS database.
- <u>The X-Form</u> is another template that has been designed for the codification of ASRS reports. It contains additional descriptors that are intended to address human-factors issues that had not been considered in the design of the original ASRS codification, but have since become of high interest. The X-Form has never been implemented for routine operation in the ASRS.
- <u>The Cinq-Demi methodology</u> (described in Appendix B) was developed during the 1980s as a tool for analyzing aeronautical-incident reports from a human-factors point of view. This methodology focuses on identifying conditions that have a high probability of leading to human errors. In 1997, a codification form was designed, built upon the ASRS codification, but with additional fields to make the codification more compatible for efficient search and analysis using the Cinq-Demi methodology. Small sets of ASRS reports have been codified using this tool and are available.

As highlighted in Wiegmann and von Thaden (2003), most incident reports are highly informative about what happened but give much less definitive information about why an incident happened. In a first-level filtering of a clustering process, we need to be able to cluster incident reports reliably on the basis of similarities of what happened. Our assumption is that this step can be achieved by the use of the taxonomic structure.

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[18] By taxonomic structure we mean a set of structured terms that describes some domain or topic as in Swartout et al. (1997). The idea is that a taxonomic structure provides a skeletal structure for a knowledge base.

[19] Codification refers specifically to the attributes and their values that constitute the fixed fields of the reporting form.

Therefore, our first objective was to identify all the possible terms of the taxonomy and their structure for the incident reports in our world of aviation. Each term will map to a parameter in the description of our world in the incident model (described in Section 3). Moreover, for every parameter used, we can state whether the concept captured is objective or not. We will call a concept ***objective*** if it can be defined on the basis of ***observable*** data. All the concepts that are not objective are called ***subjective***.

Our hypothesis is that a "full and complete" set of ***objective*** parameters adequately describes the *what* and could be incorporated into the fixed fields of a well-designed computerized reporting form for electronic submission. Then the first step of the clustering process (on similarities of the *what*) could be totally automated. The understanding of the *why* will rely on ***subjective*** parameters and on exploitation of the free text.

In Appendix D, we will discuss the merger of all the parameters identified in the three codifications, and we will assume that the result constitutes a "full and complete" set of parameters for the description of any and all aviation incidents in our world. However, as these three codification schemes entail structured sets of descriptors, we will, in this appendix, first compare these codifications at the highest levels of their structures.

C-1. High-Level Structure of the Three Codifications

In this section, we are going to study separately the taxonomic structures of the three codification forms for the ASRS reports. We will classify the type of information contained in the main sections of the three forms into the following five categories as the highest level of their structures:

1. **Time and Setting:** We group in this category all the information related to the frame of the story (when, where…) and to the fixed entities (facilities, equipment…).
2. **Cast of entities:** This category contains information on the persons and all the entities that evolve and take action in order to create the story.
3. **Anomaly:** This pertains to all the information that explains why the "anomalous state" is anomalous.
4. **Transitions:** This is all the information that characterizes a transition in the State/Transition model.
5. **Other:** This includes any information that cannot be classified in any of the other four categories.

The main purpose of these five categories is to better understand the main similarities and differences among the three codifications in their structures and their relations to the State/Transition model. Some sections of a codification form may address several categories, and then we will go one step down into the knowledge structure to understand their differences.

For each codification form, we are also going to highlight the codified links between the main sections of their structures. Our focus in this study on the high-level structure and linkages will, of course, not reveal the relations between pieces of information at lower levels in the taxonomic structure.

C-1.1 ASRS Codification

The ASRS fields are organized into the following nine main sections:

1. **Time**: The time section gives the date, the day, and the local time of day for incident occurrence. The local time is given only as a six-hour time interval, and we can assume for almost all incidents that the entire story occurs during this interval of time. This section of the ASRS codification is part of our “Time and Setting” category.
2. **Place**: The place section contains 4 subsections (Locale Reference, State Reference, Relative Position, and Altitude). We can assume that the entire story is linked to the same State Reference and Local Reference. However, the Relative Position and the Altitude subsections describe a very precise point of the space, and that point is identified with the anomalous state reached during the story. This section is in the “Time and Setting” category.
3. **Environment**: This section describes the weather, light, visibility, ceiling, and runway visual range (RVR) and falls in the “Time and Setting” category. In the spirit of the ASRS codification, the environment section relates to the weather conditions that are generally presumed not to change during the course of events of the reported incident. Nevertheless, some incident reports describe a rapid deterioration of the weather conditions, and in such cases these parameters could vary.
4. **Aircraft**: Aircraft are, of course, central elements in an aviation incident. Their descriptive parameters evolve with time, and the incident report often describes their different states. We point out that their description in the ASRS codification contains fields that are not intrinsic characteristics of the aircraft but are linked with other “elements” of the story (e.g., Controlling Facilities, Coordinating Facilities, etc.). These elements will be studied in section C-2. For the most part, an aircraft is considered as an entity in the ASRS codification, and therefore this section falls within the “Cast of entities” category.
5. **Component:** A component is one part of an aircraft. The link between the component and the aircraft is well codified in the ASRS form. The ASRS form puts the component in a separate section for historical reasons. For the purpose of this discussion, we consider the component as a part of the related aircraft entity. This section falls into the “Cast of entities” category.
6. **Person:** People are the other essential entities of the story. This section also falls in the “Cast of entities” category. Some of the subsections of the ASRS form are used to link the described person to other entities (e.g., aircraft).
7. **Events:** The events section describes several things, including the anomalous state(s) encountered in the story and the following actions that resulted in recovery to a safe state. Consequently, some of the subsections of the ASRS “Events” are in the “Anomaly” category, others are in the “Transitions” category, while some belong to the “Other” category.
8. **Maintenance Factors:** The maintenance factors section is dedicated to incidents occurring during maintenance operations. It is not within the scope of this study, and this section is omitted from further consideration.
9. **Assessments:** The assessments section is mainly an expert’s judgment about the main factors that caused this world to reach the anomalous state. It emphasizes some parts of the other fields used to describe the story (e.g., an aircraft, a person, an environment factor, etc.). It is a

judgment about the importance of some particular part of the description and so falls in the fifth category for purposes of this discussion.

Figure C-1 shows the contributions of these sections of the ASRS codification form to the categories of the information matrix and to the descriptions of the components of the Incident Model.

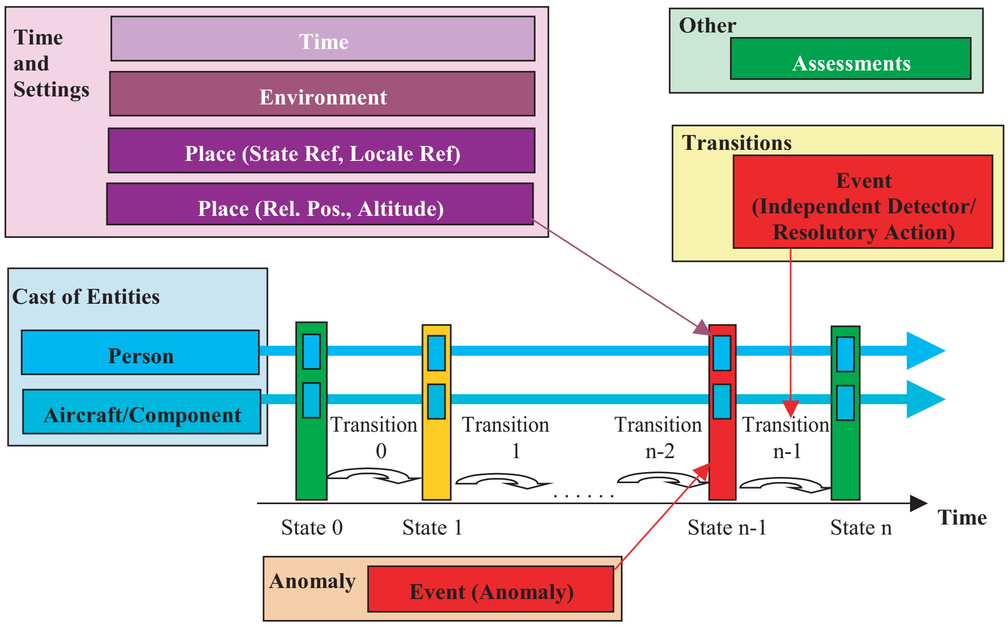

Figure C-1. The categories of information, the sections of the ASRS form, and the incident model.

As already mentioned, some links between parts of knowledge are explicitly codified in the ASRS form. Others are only implicit. Figure C-2 shows the links that are both explicit and completely defined in the ASRS form.

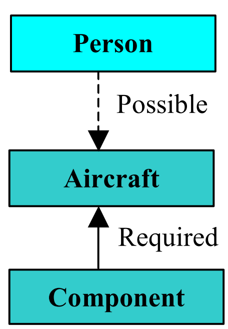

Figure C-2. Explicit links in the ASRS form.

Other more or less implicit links also exist in the ASRS database. We can point out three types of such links:

- Links between parameters describing the anomaly and one or several entities in order to describe an anomalous state (for example, an anomalous state described by "Ground Incursion" should be linked to an aircraft). These links are often implicit.
- Links between an event and one or several entities. For example, the Resolutory Action "Diverted to Alternate" is associated with the Flight Crew in the ASRS codification (because "Diverted to Alternate" is an entry in the "Flight Crew" subsection). Nevertheless the link between the event and the entity is only partly explicit as the story might contain several flight crews.
- Links between entities and other entities that are "not well defined." For example, the sub-section, "Controlling Facilities," links the aircraft with something (tower, TRACON…) that is not clearly codified in the ASRS form (there are no descriptors for the tower, TRACON…).

C-1.2 The X-Form

The X-Form is another template that has been developed for the codification of ASRS reports. It was designed to overcome some of the shortcomings of the ASRS form that had been identified after several years of use. The X-Form has never been implemented at ASRS. The definition of the required or possible links between the main sections, and how these links are codified, is not always clear.

The X-Form is organized into the following 18 sections:

1. **Record Control**: This groups information that enables good management of the database (accession number, type of codification, etc.). This section is not directly related to the description of the story and falls in the "Other" category.
2. **Time**: "Time and Settings" category.
3. **Place**: This is similar to the Place section in the ASRS Form. It is a part of the "Time and Setting" category. It contains both a general description of the location and a precise description of the place of the anomalous state.
4. **Environment**: This section describes the weather, visibility, terrain, etc., and is part of the "Time and Settings" category.
5. **Traffic**: This describes the overall air/ground traffic at the time of the story. It is part of the "Time and Settings" category.
6. **Airspace**: This describes the Airspace involved in the story. Therefore, at least one aircraft should be linked to each airspace that is involved, and each aircraft involved should be linked to at least one airspace. The notion of Airspace is similar to the notion of Place (it is a division of the space) and falls in the "Time and Settings" category.
7. **Facility-Arpt**: An airport is a fixed entity (as is the "Ground" in the Cinq-Demi codification) and so is part of the "Time and Setting" category.

8. **Facility-NAVAID**: As for the airport, it is a fixed entity and a part of the “Time and Setting” category.
9. **Facility-ATC**: As for the airport and the NAVAID, it is a fixed entity and a part of the “Time and Setting” category.
10. **Aircraft**: Falls in the “Cast of Entities” category. It contains both static and dynamic parameters.
11. **Person**: The person section falls in the “Cast of Entities” category, but the HUMPERF (Human Performance) subsection of Person describes actions made by the person. So the HUMPERF subsection is part of the “Transitions” category.
12. **Info-Probs**: This section describes events linked to a communication problem. This specific type of event has been added in the X-Form as it seems to entail crucial steps leading to an anomalous state. These events are always linked to at least one person. It falls in the “Transitions” category.
13. **Conflict**: This section describes the anomalous state and so is part of the “Anomaly” category.
14. **Adverse Interaction**: This section contains three parts: Interpersonal, Proximity, and Coordination. The second one, Proximity, characterizes the proximity of the airspace to an airport and can be considered as part of the “Time and Settings” category. The two other parts describe adverse interactions between persons or a coordination failure. They are more related to the description of the sequence of events and are classified in the “Other” category.
15. **Event Flow**: This section describes both the anomalous state (“Anomaly” category) and the following events (“Transition” category).
16. **Situation**: This section is codified only for reports related to a recurrent event or to a situation (the “same” situation has already been encountered several times in the last months). Its aim is to identify a “latent fault” in the system (policy, procedure, etc.) and is a little like some elements of the RAFT in the Cinq-Demi codification. It falls in the “Other” category.
17. **ATC**: This section contains two parts. The first one, ATC-HANDLING, describes actions taken by the ATC and is part of the “Transition” category. The other one, AIR TRAFFIC INCIDENT, mixes anomalous state descriptions (e.g., NMAC) and judgments about the role of the persons (PLT-DEV, INTERCOORD…). We are going to put this second subsection in the “Other” category (partly because, in the ASRS form, the Air Traffic Incident subsection was in the ASSESSMENTS section.).
18. **General Assessment**: This is a judgment about the importance of some factors already codified and so falls in the “Other” category.

Figure C-3 shows the relationships of the sections of the X-Form to the categories of information and to the descriptions of the Incident Model.

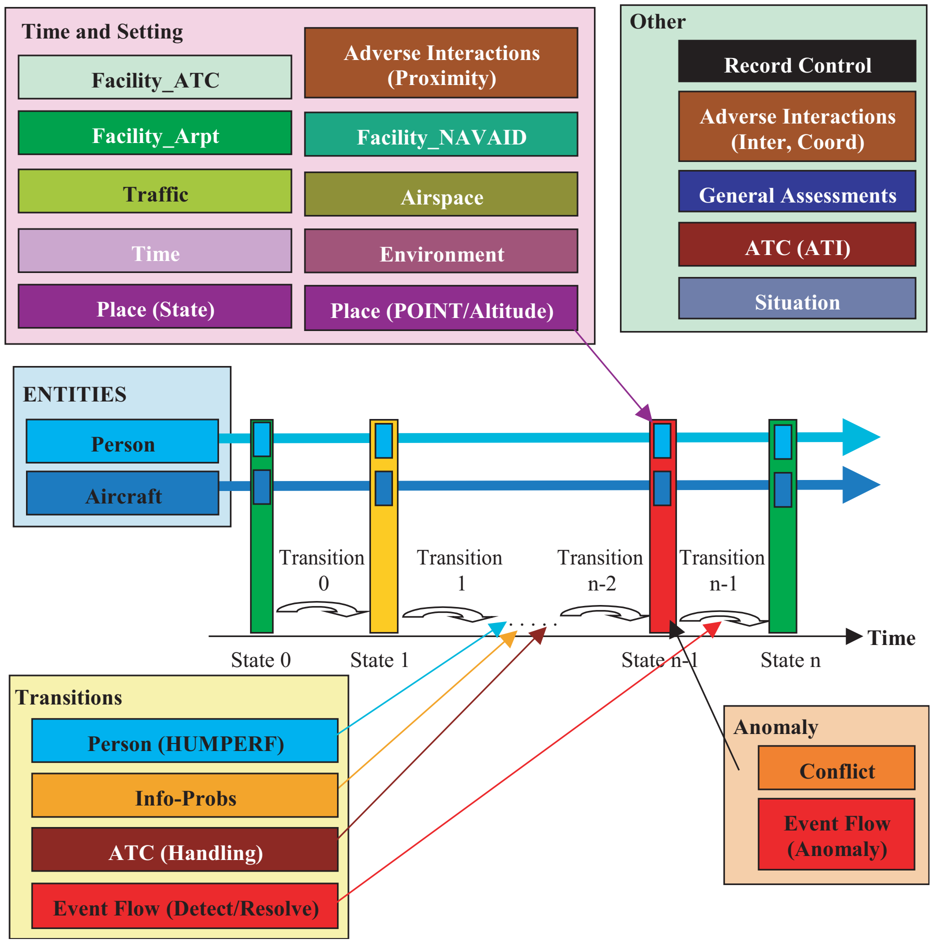

Figure C-3. The categories of information, the X-Form sections, and the incident model.

Even if the links between the sections of the X-Form are not always clearly codified, we should have at least the ones shown in figure C-4.

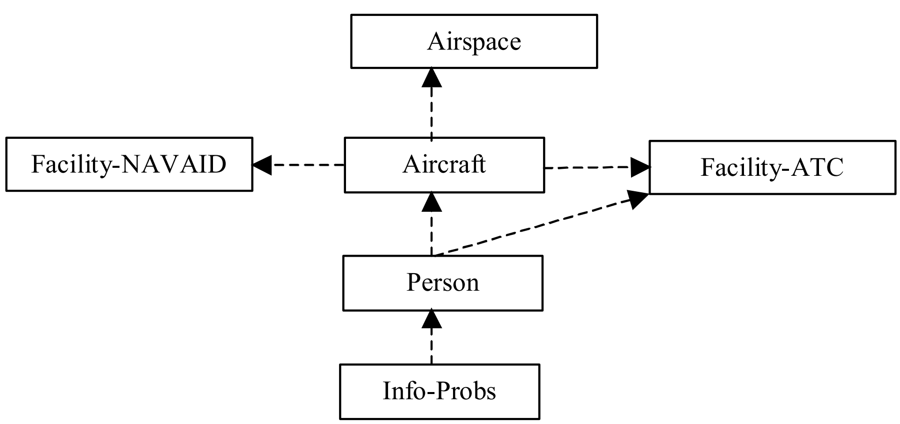

Figure C-4. The links between the sections of the X-Form.

There are other links included in the codification as, for instance, between the Info-Probs section and other sections; this is because a communication problem can entail an equipment problem. We will discuss later how to represent the elements of the "Transition" category in order to retain all the necessary links.

C-1.3 Cinq-Demi Codification

A description of the Cinq-Demi methodology is presented in Appendix B, and the structure of the Cinq-Demi codification designed for use on ASRS reports has already been extensively reviewed in previous studies (Maille 2001a and 2001b). The Cinq-Demi codification contains mainly three sorts of information: the description of the frame of the story ("Time and Settings" category), the description of the entities ("Cast of Entities" category) and the descriptions of events related to the persons ("Transitions" category). The Cinq-Demi codification primarily relies on two types of entities: aircraft and person. Their possible links are well identified and formalized. The "Ground" environment is highlighted in the Cinq-Demi formal codification, and some equipment problems can be linked to it. The "Ground" refers to the airport facilities and equipment and so we consider it to be part of the "Time and Setting" category.

Cinq-Demi's field called "Theme" is sometimes an "Anomaly" description and sometimes a "Transition" description. The confusion over the meaning of this field was, in fact, the origin of the discussions that led to the scenario concept described in this report, and so it will not be considered further.

Figure C-5 shows the relationships of the sections of the Cinq-Demi codification to the categories of information and to the description of the Incident Model.

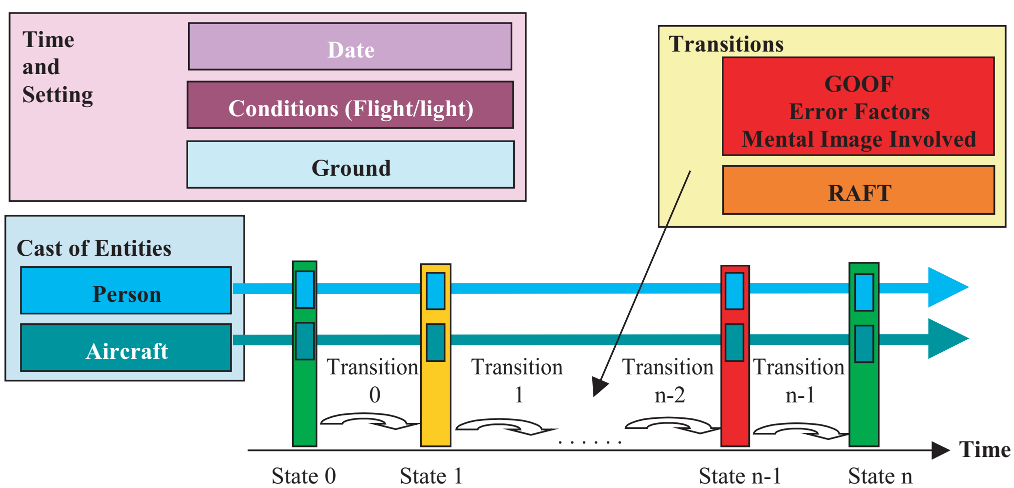

Figure C-5. The categories of information, the sections of the Cinq-Demi codification, and the incident model.

An important difference between the ASRS and the Cinq-Demi codifications is that the persons encoded are not exactly the same. The Cinq-Demi codification identifies only the categories of persons involved in an error rather than the individuals.

C-2. Comparison of the Three Structures

Each one of the three structures has some special characteristics, but their high-level organizations are quite similar. We must keep in mind that these forms are used to codify the report primarily for efficient retrospective search of the database and not as the sole basis of an in-depth analysis of the incident. That is why they include neither a precise description of the sequence of transitions, nor an accurate time reference of events or states. We are now going to describe the differences among the three forms for each category of information, and we will define the taxonomic structure that seems to be the most relevant for purposes of our study. Our objective is to define a taxonomic structure that supports both efficient retrospective search and the in-depth analyses that are the subject of this report. The sections used in the ASRS codification are all included in the X-Form's sections. The Cinq-Demi codification introduces two new sections (GOOF and RAFT) for the description of the transitions.

- "Cast of entities": The three codifications do not entail exactly the same entities, but all three refer to the notions of Person and Aircraft.
  - Person: The Cinq-Demi codification highlights only groups of persons that have made some error, and their codification is designed for understanding conditions that lead to human error. As the ASRS reports are primarily used for an operational analysis of incidents, it is certainly better to encode all the persons involved in the incident. Nevertheless, we will have to be sure that our codification allows us to identify which persons have made an error. (The links between the fields used to describe the error or the conditions leading to the error, and the person or team responsible for the error, must be clearly codified.)
  - Aircraft: The only difference among the three forms is that the ASRS codification has a separate section for the description of an aircraft component. We point out that the information related to the component is often more related to a description of an event (malfunctioning, failed, improperly operated…) than it is to a description of the aircraft. As we want to highlight the transitions (the why and the how), we propose to group such information with the other transitions (as in the Cinq-Demi grids where the Technical Failure (Span) is classified as one of the possible perturbations).
- "Time and Setting": The most complete description is the one used in the X-Form. We are going to use the sections of the X-Form as a starting point for this category.
- "Transitions": In our analysis of the three forms, we put the information related to the "Transitions" (at least the one involving a person) in a separate category, but in the templates that information can be:
  - incorporated in another section (for instance HUMPERF is a subsection of the PERSON section), or
  - in a specific section (e.g., INFO-PROB section).

  Incorporating the transition information into another section enables us to relate it to the other information of that section. This is used to highlight two sorts of links:

– The link between the transition and the person responsible for that transition (for instance HUMPERF subsection). Thus the actor performing the action is unambiguously identified.

– The link between the transition and a specific state. (For instance, the "Resolutory Event" subsection of the ASRS form is in the same section as the "Anomaly" and the "Independent Detector" subsections, highlighting their link.)

Incorporating the transition information within a person description raises two problems:

– It does not allow a good codification of an event linked to several persons (such as communication problems).

– It does not allow an easy representation of the sequence between the events (even if we do not know yet whether we really want to codify such a sequence in a codification process) or an easy retrieval of how things happened.

As we assume that a "good" schemata that captures the essence of the story of the incident is that of the Scenario (i.e., Context + Behavior → Outcome), we propose to clearly separate in the taxonomic structure all the information related to the transitions and, therefore, to Behavior. The "Resolutory Action/Event" must be identified separately (as it is done in the X-Form and in the ASRS form) because it is not part of the "Behavior" of our Scenario. For our current study, the Outcome of the Scenario is an anomalous state and the Behavior of recovery to a safe state is not a part of this study. The Scenario that includes consideration of recovery from an anomalous to a safe state will be the subject of a subsequent study.

- "Anomaly": This is described in a very similar way in the ASRS and in the X-Form. The two descriptions will be merged for our structure.
- "Other": Having a separate section for record control seems to be a good idea. The other sections (e.g., Assessments, Situation) have to be consolidated depending on the aim of our codification.

The overall taxonomic structure of the knowledge and its links with the three parts of the Scenario are shown on figure C-6.

C-3. A "Full and Complete" Set of Parameters

In section C-2, we compared, at a high level, the taxonomic structures that underlie the three codification forms specifically designed for ASRS reports. We showed that the structure of the knowledge used in the ASRS codification is embodied in the one used by the X-Form. Therefore, we will use the X-Form structure on which to map all the parameters used in all three forms. Parameters that are addressed only in the Cinq-Demi form will be inserted at the most relevant place in that structure.

The set of all the parameters of this taxonomic structure is given in Appendix D.

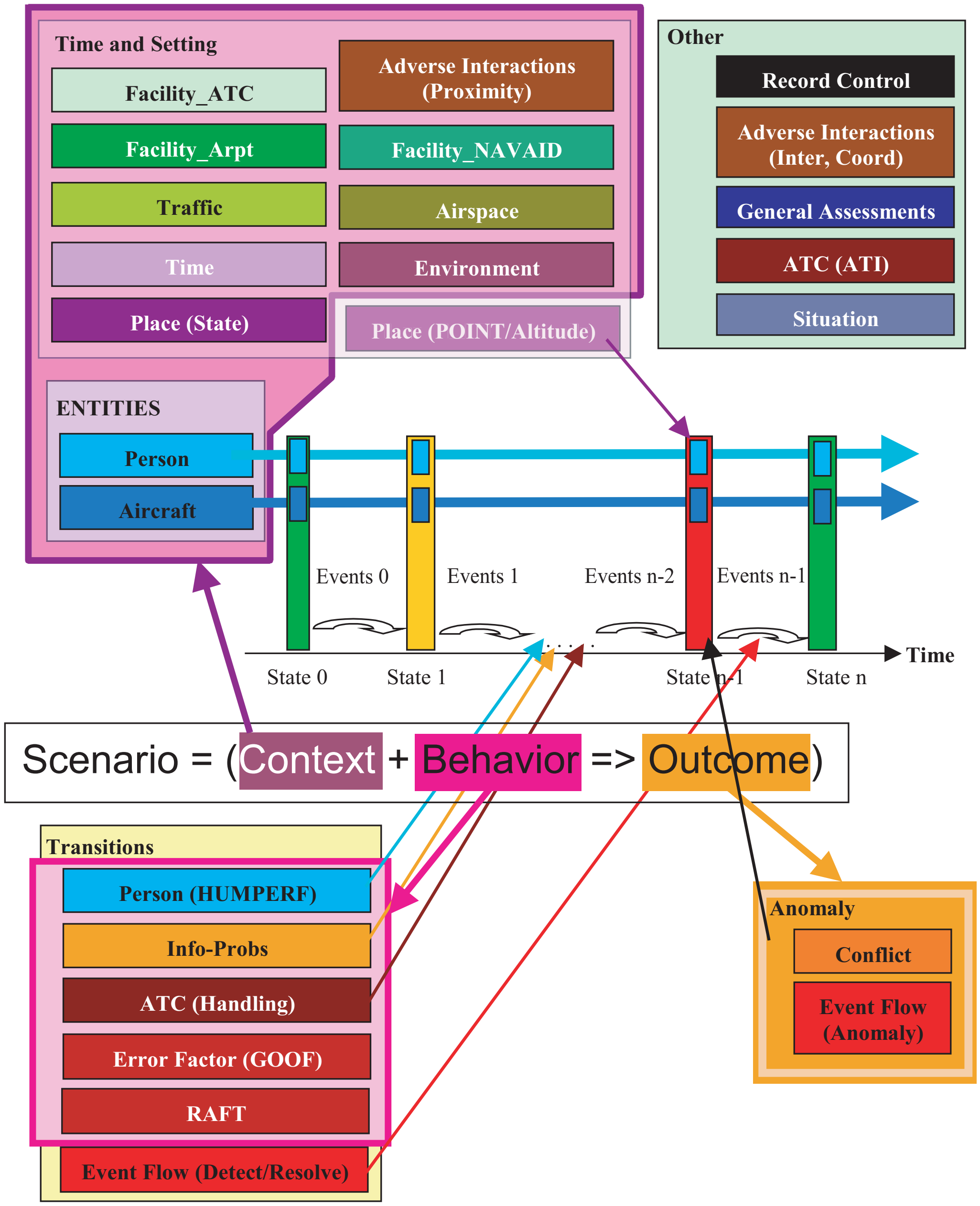

Figure C-6. Main relations between the Scenario and the categories of information.

APPENDIX D: MAPPING PARAMETERS TO A "FULL AND COMPLETE" SET

This appendix describes the process of formulating a "full and complete" set of parameters based on a consolidation of those that have been identified in (1) the current ASRS codification form, (2) the Cinq-Demi GRIDS, and (3) the "X-Form." All of these parameters have been classified according to the five categories of information (Time and Setting, Entities, Anomaly, Transitions, and Other) and their sub-categories as shown in figure 6. A separate table of parameters is built for each sub-category.

Moreover, this set of factors has been separated into the following two categories:

1. Factors that are clearly and unarguably objective, categorical, and measurable (for simplicity, these will be called "objective" factors in this presentation).
2. All the others (that, for the moment at least, we will simply label as "subjective").

We need not seek "perfection" in this process of classifying parameters as objective or subjective. Certainly, there are factors that everyone would put in category 1 that could have an aspect of subjectivity (such as visibility, for example). Certainly, there will be differences of opinion on where to assign some factor, but we do not consider this degree of uncertainty to be very important to the result because the number of questionable factors constitutes only a small portion of the total number of parameters.

In each of the following tables, the titles of the tables should not to be confused with the fields. The fields (or the attributes) associated with each title are in yellow cells. The parametric values of these attributes are shown in white cells if they are objective parameters or in green cells if they are other than objective (called subjective) factors.

Time and Setting

Time	
Date of Occurrence	
Day of Occurrence	
	SUN
	MON
	TUE
	WED
	THU
	FRI
	SAT
Time of Occurrence	
	0001 to 0600
	0601 to 1200
	1201 to 1800
	1801 to 2400

Place			
State Ref.			
Local Ref.			
	Facility		
		ID	
		Type	
			ARPT
			VOR
			VORTAC
			NDB
			TACAN
	Intersection		
	Special Use Airspace		
Relative Position			
	Distance		
	Radial		
	Angle		
Altitude			
	MSL		
	AGL		

Environment	
Flight Conditions	**Lighting**
VMC	Dawn
IMC	Daylight
Mixed	Dusk
Special VFR	Night
Marginal	**Visibility in Statute Miles**
Ceiling	Low Boundary (statute miles)
CLR	Upper Boundary (statute miles)
Single Value (feet)	Single Value (statute miles)
Lower Boundary (feet)	**Runway Visual Range**
Upper Boundary (feet)	Lower Boundary (feet)
WX-AVD	Upper Boundary (feet)
Weather Elements	Single Value (feet)
Wind Fx	**Terrain Fx**
CLR-TURB	MTNS
WAKE	HILL
TURB	RISING
ALOFT	DITCH
SHEAR	TREE
HEAD	WIRE
TAIL	TOWER
CROSS	OTH-OBST
TSTORM	WATER
DN-DRAFT	GRADE
UP-DRAFT	CRANE
Obscur'n Fx	BRIDGE
SMOG	BUILDING
PRECIP	VEHICLE
DUST	OBS-LTG
CLOUDS	**Other Fx**
SUNPOS	BIRDS
UNDCAST	ANIMAL
OVERCAST	PED
HAZE	LTNG
OBSTRUC	LITE
FOG	SIGN
WDW	MARK
Precip'n Fx	ENGICE
RAIN	FRAMICE
TSTORM	FOB
DRIZZLE	SKYDIVER
SLEET	BARO-GRADIENT
SNOW	WXBAL
HAIL	RAPID-DETER
	JETBLAST

Facility Airport	
Involvement	
	SURF
	O&D
	COM
	PROB
Facility State	
Facility ID	
Facility Descriptors	
	PVT
	CTL
	UCTL
	CLOSED
	SATELLITE
	CONSTRUCTN-ACTIVITY
	RWYS-IN-USE-PAR
	RWYS-IN-USE-INTER
	RWYS-IN-USE-CVG
	RWYS-IN-USE-DVG
	RWY-CHG-IN-PROGRESS
	CRASH-ACTIVATED
	HELIPORT
	SEAPLANE
Problem Components & Services	
	RWY
	TXWY
	RAMP
	SURFACE
	WX-EQP
	COM-EQP
	COM-ENV
	INTXN-NAME
	DMEN
	SRVCS
	PROC-POL
	STAFF
	MGMT

Facility ATC	
Involvment	
	CTRL
	NBRQ
	COM
	PROB
Facility Type	
	TWR
	TRACON
	ARTCC
	MILFAC
	FSS
	CPNY-RDO
	CTAF
	UNICOM
Facility State	
Facility ID	
Facility Descriptors	
	DARC-ACTIVATED
	BUEC-ACTIVATED
	TRNG-IN-PROG
	CRASH-ACTIVATED
	CLOSED
	NON-RDR
	NON-FED
Problem Components & Services	
	RADAR
	COM-EQP
	COM-ENV
	OTH-EQP
	COMPUTER
	STRUCTURE
	SRVCS
	STAFF
	PROC-POL
	SCOPE
	MGMT

Traffic	
OPPDIR	UNKVFR
SAMEDIR	POPUP
SIDEBY	UNAUTH
CONVERG	PLTDEV
INTERSEC	FLTASSIST
PARALLEL	EMER
SAMEALT	SPC-EVENT
OVERTAKE	BOUNDARY
PERFDIFF	TFC-SEQ
CONGEST	CROSSING
FLYWAY	FORMATION
OVERFLT	FORM-BREAKUP
NORAC	FORM-JOINUP
NORDO	CLOSURE-RATE

Airspace	
Involvement	Routes (cont'd)
OCCU	Arrival
SHUD	Profile Descent
ENT	Holding Pattern
EXIT	STAR
PROB	On Vectors
Airspace ID	VFR
Type	Approach
Class A	Circling
Class B	Contact
Class C	Instrument Precision
Class D	Instrument Non Precision
Class E	SVFR
Class G	Traffic Pattern
Special Use	Visual
Temporary Use	Charted Visual
SUA (Special Use Airspace)	Straight-In
PROHIB	Military
RESTR	Transit
REFUEL	OverWTR
WARN	IAPS
SR	ILS
ALERT	VOR
MOA	NDB
VR	MLS
IR	PARALLEL
OSUA	RNAV
DZ	SDF
ROUTES	TACAN
Departure	Design Problem
SID	MAP-PT
Noise Abatement	INTXN-NAME
Other Published IFR Departure	APCHES
On Vectors	DEPS
Enroute	CHARTING
Airway	XING-ALT
Direct	PROX
On Vectors	HMDG
Atlantic	
Pacific	
Other Oceanic	

Facility NAVAID
Involvement
NAV-ERR
COM
PROB
Facility Type
ILS
VOR
VORTAC
NDB
TACAN
BCSTN
LDIN
ROT-BEAC
MLS
LORAN
SATELLITE
OMEGA
OTH-VIS
Facility State
Facility ID
Problem Components & Services
ILS
COM-EQP
COM-ENV
LITE
SRVCS
STRUCTURE

Adverse Interactions
Proximity Btwn Terminals & Airspc
Civil-Mil Arpt
Civil-Civil Arpt
Route-Terminal
Route-SUA
Bird Flyway-Terminal
Canadian Airspace
Mexican Airspace

Entities

Aircraft

- **Make Model**
- **Aircraft Type**
  - SMA
  - SMT
  - LTT
  - MDT
  - MLG
  - LGT
  - HVT
  - WDB
  - FGT
  - BMB
  - MLT
  - MTR
  - SPC
  - ULT
  - SPN
  - BAL
  - HNG
  - OTH
- **Crew Size**
  - 1
  - 2
  - 3
  - 4OM
- **Airframe**
  - wings
    - WL
    - WM
    - WH
    - WB
    - WO
    - WR
  - gear
    - LN
    - LR
    - LF
  - surf mod
    - SL
    - SS
    - SA
    - SI
  - engines
    - ER
    - ET
    - EJ
    - EN
- **Number of Engines**

- **Advanced Ckpt**
  - DISPLAY
  - NAVCTL
  - NON
- **Operator Organization**
  - Common Carrier
    - Air Carrier
    - Air Taxi
    - Charter
  - General Aviation
    - Corporate
    - Instructional
    - Personal
  - Other
    - Government
    - Military
    - RNT
- **Mission**
  - Passengers
  - Freight
  - Training
  - Pleasure
  - Agriculture
  - Ambulance
  - Ferry
  - Test Flight
  - Tactical
  - Refueling
  - Traffic Watch
  - Other
  - Banner Tow
  - Business
  - Photo-Shoot
  - Repositioning
  - Skydiving
  - EMS
  - CBO
  - CKD-RID
  - FLT-CHK
  - UTL
  - PRB
- **Flight Plan**
  - VFR
  - IFR
  - DVFR
  - SVFR
  - COM
  - NON

Aircraft (cont'd)	
Flt Phase	**Flt Phase (cont'd)**
GND	ARR
PREFLT	DSCNT
PUSH-BK	APCH
POWER-BK	LNDG
TAXI	HLD-SHT
GND-HOLD	AIR-HOLD
HLD-SHT	MNTN
INTXN-XING	PATTERN
Parked	GAR
Maintenance	SHT-FLD
Holding	OFF-ARPT
Position and Hold	MAP-PT
Takeoff Roll	PARK
DEP	LOW
TKOF-POS	TAG
TKOF	INTXN-LNDG
ABORT	DN-WIND
INTXN-TKOF	SIDESTEP
ICLB	Intermediate Altitude
CLB	Vacating Altitude
DN-WIND	Roll
SHT-FLD	Missed Approach
OFF-ARPT	**Operating Under FAR Part**
MITO	Part 91
Intermediate Altitude	Part 119
Vacating Altitude	Part 121
CRS	Part 125
WX-AVD	Part 129
VECTOR	Part 135
DIV	Other Part
DIRECT	**Maneuver**
Level	Imposed by Mission
Holding	Speed
Enroute Altitude Change	Angle
MNV	Heading
TURN	Altitude
180	Configuration
360	Correction
AUTO-ROT	Speed
LLL	Angle Attack/Longi.
LLH	Sideslip
TOW	Lateral Attitude
OTH	Heading
EMER	Altitude

Aircraft (cont'd)

Routes

- Departure
  - SID
  - Noise Abatement
  - Other Published IFR Departure
  - On Vectors
- Enroute
  - Airway
  - Direct
  - On Vectors
  - Atlantic
  - Pacific
  - Other Oceanic
- Arrival
  - Profile Descent
  - Holding Pattern
  - STAR
  - On Vectors
  - VFR
- Approach
  - Circling
  - Contact
  - Instrument Precision
  - Instrument Non Precision
  - SVFR
  - Traffic Pattern
  - Visual
  - Charted Visual
  - Straight-In
- Military
- Transit
- OverWTR

Navigation in Use

- ILS
  - Localizer Only (RWY ID)
  - Localizer & Glideslope (RWY ID)
- VOR
- NDB
- FMS or FMC
- GPS
- INS
- Loran
- Pilotage
- DME

Descriptors

- FGN-FLAG
- FORMATION
- ORDNANCE-ON-BOARD

Approach

- CAT-I
- CAT-II
- CAT-III
- BC
- LDA
- MLS
- PAR
- RNAV
- SDF
- TACAN
- OHD
- OPPDIR
- INIT
- FINL
- SHT-FINL
- NON-RDR
- PRACTICE
- DN-WIND
- UP-WIND
- SIDESTEP

Cabin Activity

- Beverage Service
- Boarding
- Cart Service
- Deplaning
- Meal Service
- Movie
- Safety Related Duties
- Seated
- Tray Service
- Other (activity)

Cabin Lighting

- Bright
- Medium
- Dark

Available Seats

Pass. on Board

Maintenance Status

- Required Documentation on Board
  - No
  - Yes
- Released for Service
  - No
  - Yes
- Maintenance Deferred

Aircraft (cont'd)	
Problem Systems	ATA Code
Placard/Marking	Manufacturer
Servicing	Problem
Air Conditioning	Design Deficiency
Auto Flt	Failed
Communications	Improperly Operated
Electric Power	Malfunctioning
Eqp/Furnishings	Not Installed
Fire Protection	Aircraft Problems
Flt Ctls	CKPT-NOISE
Fuel	MTNC-DISCREPANCY
Hydraulic Power	DECOMPRESSION
Ice/Rain Protect	FIRE
Indicating/Recording Sys	ACFT-PERF
Landing Gear	PREFLT-DEICING
Lighting	ENG-OUT-PERF
Navigation (+ FMS)	CONFIGN
Oxygen	FLEET-INCONSIST
Pneumatic	DESIGN
Vacuum	CABIN-SPACE
Water/Waste	VIS-SIGNATURE
Electrical Panels & Parts	INSPECTION
APU	CREW-COMPLEMENT
Doors	
Fuselage	
Nacelles/Pylons	
Stabilizers	
Windows	
Wings	
Propeller	
Rotor	
Pwe Plant	
Eng Fuel Ctl	
Ignition	
Air	
Eng Ctls	
Eng Ing/Warning	
Exhaust	
Oil	
Starting	
Turbines	
Water Induction	

Person	
Person's Involvement	**Function at Tme of Occurrence (cont'd)**
Pilot Flying	Controller
Pilot Not Flying	Local, Combined Local
Monitoring	Local, Combined Local
Controlling	Ground, Combined Ground
Cabin Service	Ground, Combined Ground
Evaluating	Flight Data
Instructing	Clearance Delivery
Receiving Instruction	Departure
Maintenance	Approach
Observing	Radar
Other Direct Involvement	Combined Radar
Affiliation	Non Radar
Government	Handoff Position
FAA	Traffic Management
Foreign	Flow
Military	Maintenance
Company	Inspector
Air Carrier	Technician
Air Taxi	Lead Technician
Charter	Flight Attendant
Corporate	On Duty
Other	Off Duty
Contracted Service	Extra
Instructional	MILFAC
Personal	PAR
CGA	RANGE
NGA	RSU
UGA	OTHER
Function at Time of Occurrence	FSS Specialist
Oversight	UNICOM Operator
PIC	FBO Personnel
Supervisor	Vehicle Driver
Coordinator	Dispatcher
Flight Attendant in Charge	Gate
Airport Manager	Ramp Guidance
Observation	CGP
Air Carrier Inspector	CENR
Company Check Pilot	**Qualifications**
Observer	Pilot
Passenger	Student
Instruction	Private
Instructor	Instruments
Trainee	Multi-Engine
Flight Crew	Commercial
Single Pilot	ATP
Captain	CFI
First Officer	Flight Engineer
Second Officer	Military
Relief Pilot	
Navigator	
Load Master	

Person (cont'd)

Qualifications (cont'd)

- Controller
  - Military
  - Radar
  - Non Radar
  - Developmental
  - SPI
- Technician
  - Repairman
  - Powerplant
  - Airframe
  - FCC
  - Inspection Authority
- Flight Attendant
  - Currently Qualified
  - Trainee
  - Aircraft Qualified on (number)
- Other
  - FSS Specialist
  - Dispatcher

Experience

- Controller
  - Radar
  - Non Radar
  - Supervisor
  - Military
  - Limited Radar
  - Time Certified in Pos 1
  - Time Certified in Pos 2
  - General/Total
- Dispatch
- FSS Specialist
- Flight Attendant
  - Total
  - Airline Total
  - Type
- Maintenance
  - Repairman
  - Technician
  - Lead Technician
  - Avionics
  - Supervisor
- Flight Time
  - Total
  - Last 90 Days
  - In Acft Type

Factors Adversely Affecting Perf.

- Physical Factors
  - External Factors
    - Reduced Comfort
      - Workspace
      - Seats
      - Abnormal Body Position
      - Under Hood
    - Embarrassing Working Suit
      - Safety Suit
      - Gloves
      - Boots
      - Earphones
    - Work Station Motion
      - Vibration, Shakes
      - Low Freq. Oscillations
      - Load Factor
      - Rate of Climb
      - Rate of Descent
    - Environment
      - Temperature
      - Cabin Pressure
      - Humidity
      - Lighting
      - Background Contrast
      - Audio Interferences
      - Noise
      - Visual Interferences
      - Smell
      - Smoke
    - Time at Incident Occurrence
      - Mission Beginning
      - Mission End
      - Back from Vacations
      - Before Vacations
      - During Vacations
      - Schedule Changes
      - Duty Cycle Length
      - Shift-Chg
  - Internal
    - Medicines
    - Alcohol
    - Drugs

Person (cont'd)

Factors Adversely Affecting Perf. (cont'd)

- Physiological Factors
  - Fatigue
  - Needs
    - Hunger, Thirst
    - Natural Needs (toilets)
  - Pathological Status
    - Sickness, Flu
    - Aches
    - Itching
    - Obvious Incapacitation
    - SUB Incapacitation
    - Vertigo
    - Hypoxia
  - Illusion
    - Yehudi
    - Black-Hole
    - White-Out
    - Sloping-Ter
  - Disorientation
- Sociological Factors
  - Internal Factors
    - Crew or Team Structure
    - Qualification
      - Unqualified
      - Not-Current
    - Occasional Manpower Shortage
    - Team Internal Dispute
    - Proficiency
      - In-Doubt
      - Learner, Beginner
      - Training Deficiency
      - Recency-of-Experience
    - Language Barrier
    - Familiarity
      - ARPT
      - ATC-PROC
      - EQP
      - AREA
      - TERRAIN
      - ACFT-PERF
      - WX
      - AIRSPACE
      - REGS
      - NAVAID
      - ARPT-PROC
      - CHART
      - NEW

Factors Adversely Affecting Perf. (cont'd)

- Sociological Factors (cont'd)
  - External Factors
    - Bad Social Environment (Strike)
    - Visitor
    - Instructor
    - Inspector
    - VIP
    - CPNY-BUS
- Psychological Factors
  - Fear, Anguish
  - Personal Troubles
  - Personal Preoccupations
  - Family Troubles
  - Memory Loss
  - Madness
- TASKLOAD
  - SGL-PLT
  - COMBO-POS
  - COMBO-SEC
  - CREW-COMPLEMENT
- PREOCC
  - TFC
  - WX-AVD
  - EQP-PROB
  - TRNG-IN-PROG
  - FLTASSIST
  - CHKLST
  - TUNING
  - OTH-TASK
  - SPC-EVENT
  - FUEL
- ATTITUDE
  - UNPROFESS
  - ANTAGON
  - COMPLACENT
  - GETHOME
  - AGGRESS
- RSCE-DEFIC
  - CTLR
  - SUPVR
  - FLC
  - CHART
  - PUB
  - FSS
  - NAVAID
  - ACFT-EQP
  - ATC-EQP
  - ATC-SRVC
- OTH
  - PAX-DISCOMFORT
  - PAX-ILLNESS

Anomaly

Anomaly

- Technical
  - Acft Eqp Prob
    - Critical
    - Less Severe
  - ATC Com (lost or intermittent)
  - False/Erratic Course Indic.
  - Fuel
    - Exhaustion
    - Inadequate
    - Contamination
    - Type
- Encounters
  - In-Flt Encounter
    - VFR in IMC
    - VFR over the TOP
    - Weather
    - Turbulence
    - Birds
    - FOB
    - Obstruc
    - Skydivers
    - Wake Turbulence
  - Gnd Encounter
    - FOB
    - Ped
    - Animal
    - Birds
    - Eqp
    - Jet Blast
    - Vehicle
- Deviations
  - Speed Dev
  - Alt Dev
    - Overshoot on Clb
    - Overshoot on Dscnt
    - Undershoot on Clb
    - Undershoot on Dscnt
    - Excursion Clb
    - Excursion Dscnt
    - Xing Restrict Not Met
    - Acft at Imprud Alt
    - Descent Below/MSA
  - Other Spatial Deviation
    - Track or Hdg Dev
    - Acft on Imprud Track
    - Control. Flt Toward Terrain
    - Unctrl Arpt Tfc Pattern Dev
    - Altitude Heading Rule Deviation
    - Glideslope
- Loss of control
  - Ground Excursion
    - Rwy Overrun
    - Rwy Excursion
    - Txwy Excursion
    - Ramp (Gnd Excursion)
  - Other
    - Gnd Loop
    - Stall
    - Spin
    - Hydroplane
- Maintenance Problem
  - Improper Maintenance
  - Non Compliance with MEL
  - Improper Documentation
- Tkof
  - Overweight Tkof
- Landing
  - Overshot
  - Undershot
  - Gear Up Landing
  - Tailstrike
  - Hard Landing
  - Wrong Rwy
  - Wrong Arpt
  - Landing Without Clr
  - Txwy Lndg
  - Overweight Lndg
- Apch
  - Wrong Rwy
  - Wrong Arpt
  - Unstabilized Apch
- Ground Incursion
  - Taxi
  - Runway
- Conflict
  - Airborne
    - NMAC
    - Air Less Severe
  - Ground
    - Gnd Severe
    - Gnd Less Severe
- Airspace Violation
  - Unauth Incursion
  - Unauth Excursion
  - Uncoord Penetration
  - Uncoord Exit

Anomaly (cont'd)	
Non Adhere Legal Rqmt	**Cabin Event**
Clrnc	Galley Fire
Pub Proc	Passenger
MEL	Misconduct
Wx Mins	Illness
FAR	Contraband
Alt-Hdg	Electronic Device
Alt-Setting	**Other**
Ster Ckpt	FLC Status
Speed	Hazardous Cargo Problem
Inspec	Smoke or Fire
AD	Fumes
Company Policies	CG Irregularity
Required Legal Separation	**Uncoord**
Non Comp/Srvc Advsy	Sector Penetration
	Rwy Movement

Conflict
Traffic Mix
ACFT
VEH
VSL
OTH
Flt Regime
GND
TMNL
ENRTE
Event Severity
MIN
MOD
NEAR
Miss Distance
Horizontal Miss
Vertical Miss
Diag/Unspect'd Miss

Transitions

Problematic Human Performances	
Data Collection/Transmission	Decision after Treatment
COM	PLAN
INTRA-CKPT	PREFLT
INTER-CKPT	INFLT
ATC-FLC	TFC
CPNY-FLC	APCH
INTER-FAC	BACKUP
INTRA-FAC	TFC-SEQ
CKPT-CAB	DECIDE-Y
GND-CKPT	DEP
TECHNIQ	TKOF
OBSERV	ABORT
TFC	RTN
SPACING	AVD-WX
ALT	GAR
HZ-POS	DIVERT
ATT	COMPLY
SPEED	DEVIATE
WX	TIMING
EQP-STAT	EMER
MIS-ID	LNDG
TECHNIQ	MAP
ARPT	CROSS
LANDMARK	HLD-SHT
RWY	MTN
TXWY	CLIMB
INTXN	DSCNT
WALK-AROUND	TURN
TGT	AIRHLD
CHK-PT	TKOF-POS
LOST-SIGHT	EXER-COM-AUTH
ATTITUDE	DH
HEADIN	
HEADOUT	
SCAN	
UTILIZE	
FLC	
ATC	
EQP	
FSS	
CHART	
PUB	
PF	
PNF	
SO	
DMAN	
SUPVR	
CTLR	
FLTSTRIP	
NAVAID	
STAGE3	

Problematic Human Performances (cont'd)	
Decision after Treatment (cont'd)	**Action**
DECIDE-N	EQP-USE
DEP	PROGRAM
TKOF	SWITCH
ABORT	TBLSHOOT
RTN	SETUP
AVD-WX	HANDLE
GAR	MODE-SEL
DIVERT	TECHNIQ
COMPLY	NAV
DEVIATE	INSTRUM
TIMING	DEADRECK
EMER	PILOTAGE
LNDG	TECHNIQ
MAP	CHK-PT
CROSS	MANIP
HLD-SHT	TKOF
MTN	CRS
CLIMB	APCH
DSCNT	LNDG
TURN	TAXI
AIRHLD	PATTERN
TKOF-POS	IMC
EXER-COM-AUTH	CROSS-WIND
DH	TECHNIQ
MANAGE	OTHER
PRIORITIZE	DEICING
ASSIGN	
DELEGATE	
DISCARD	
RQST-INPUT	
RSPND-INPUT	
EVALUATE	
INITIATE	
MONITOR	
FAIL-INTERV	
TERMINATE	
EARLY	
LATE	
DEV-SOP	
INFLEX	
INDECISION	
UNLOAD	
RECOGNIZE	

Information Problems

Message Origin

- PSN
  - FLC
  - ATC
  - GNDCREW
  - CAB
  - FSS
- EQP
  - ACFT
  - ATC
  - SCOPE
  - TAPE
- CHART
  - SECTIONAL
  - WAC
  - PLATES
  - IFR-ENRTE
- PUB
  - ATC-HD-BOOK
  - AIM
  - FARS
  - FOM
  - MEL
  - NOTAM
  - BULLETIN
  - LOA
  - DIRECTIVE
- OTH
  - NOTES
  - FLT-PROG-STRIP
  - DISPATCH
  - LOG

Destination

- PSN
  - FLC
  - ATC
  - GNDCREW
  - CAB
  - FSS
- OTH

Media

- DIR
  - VIS
  - AUD
  - GESTURE
- GND-EQP
  - TPHONE
  - IPHONE
  - INTER
  - INTRA
  - COMPUTER
- RDO
  - CTAF
  - UNICOM
- WRITTEN
  - LOG

Type

- DATA
  - ALT
  - HZPOS
  - SPEED
  - ATT
  - AIRSPACE
  - REGS
  - TERRAIN
  - WX
  - ARPT
  - ROUTE
  - PROC
  - BRAKING
  - FLT-PLAN
  - STORED
  - HYDRAULICS
  - FUEL
  - ACS-STATUS
  - ELECTRICAL
  - PRESSURIZATN
  - WT-BAL
- ADVSY
  - CALLOUT
  - POINTOUT
  - TFC
  - WX
  - AIRMET
  - SIGMET
  - PIREP
- CHKLIST
  - CHALLENGE
  - RESPONSE
- SQUAWK
  - 1200
  - 7500
  - 7600
  - 7700
- INSTRUC
  - CLRNC
  - AMENDED
  - CANCELLED
  - EXPEDITE
- TAPED
  - ATIS
  - TWEBS
- FEED-BK
  - CONFIRM
  - READBACK
  - ACKNOW
- QUERY
  - RQST
  - PERMSN
- PROC
  - FREQ-CHG
  - LOST-COM

Information Problems (cont'd)

Type (cont'd)

- COORD
  - HDOFF
  - BRIEFG
  - MANUAL
- INTENT
- OTH
  - IN-BLIND
  - ABBRV
  - RELAY

Reference Phase

- GND
- DEP
- CRS
- ARR
- MNV
- OTH

Problems

- CONTENT
  - FALSE
  - INCOMPL
  - AMBIG
  - MISLEAD
  - IMPRUD
  - CONFUS
- TIMING
  - NEVER
  - EARLY
  - LATE
  - OTH-PRIORITY
- XPRESSN
  - SIM-SND
  - SIM-LOOK
  - PHRASEOLOGY
  - TRANPOS
  - MISSTATE
  - CALLSIGN
  - NAME
  - NUMBER
  - VOX-QUAL
  - ENNUNC
  - CLUTTER
  - WRNG-FREQ
  - SPCH-RATE
  - LANGUAGE-BARRIER

Problems (cont'd)

- EQP
  - GND
  - AIR
  - OTS
  - WEAK
  - INTERMITTENT
- ENVIRON
  - FREQ-BLOCK
  - SIMUL-XMISSN
  - RANGE
  - STEEPED-ON
  - NOISY
  - AUD-INTERF
  - VIS-INTERF
  - FREQ-CONGEST
  - FREQ-LAP
- RECEPTN
  - WRNG-FREQ
  - NOT-OBS
  - NOT-MON
  - NOT-HEARD
  - MISSED
  - INADEQUATE-DISSEM
- INTERP
  - MIS-INTERP
  - MINDSET
  - CALLSIGN
  - NAME
  - NUMBER
  - LANGUAGE-BARRIER
- RESPONSE
  - DENIED
  - REFUSED
  - NON-COMPLY
- UTILIZN
  - FORGOT
  - DEGRADED
- OTH
  - GARBLED
  - INTERMITTENT
  - LOST-COM

ATC-HANDLING	
Clrnc	Coord
Imprud	Untimely
Misdirected	Imprud
Misstated	Misstated
LTSS Permitted	Misdirected
Uncoord	Non
Sector Penetration	Briefing or Relief
Rwy Movement	Flt Prog Strip
Advsy	Not Posted
Safety Not Sent	Late Posting
Tfc Not Sent	Not Marked
Wx Not Sent	Improper Mrkng
	Not Scanned
	Nonstandard Phraseology
	Flt Plan Handling

Misrepresentation
Ext.Environment Mod
Flight Mechanics Mod
Load./Spec. Eqpt Mod
MELMod
3D Trajectory Mod
Risk Mod
Structure Mod
Press/AirCond Sys Mod
Flight Auto Sys Mod
FMS Mod
Communicat. Sys Mod
Electrical Sys Mod
Auxiliary Eqpt Sys Mod
Flight Controls Sys Mod
Fuel Sys Mod
Hydraulic Sys Mod
Rain/Ice Sys Mod
Landing Gear Sys Mod
Navigation Sys Mod
Oxygen Sys Mod
Aux. Power Sys Mod
Powerplant Sys Mod

Operational System Fault
Organization
Responsibility
Carrying Out
Means
Drills
Design
Basic Design
Mechanical Ergonomy
Mental Ergonomy
Education
Basic Education
Specific Education
Documentation
Physical Faults
Wrong Content
Requirements

Resolutory Event

Independent Detector

- Cockpit
  - Flight Crew
  - Aircraft Equipment
    - Altitude Alert
    - TCAS
    - GPWS
    - Lite
    - Vox
    - Sound
- ATC
  - Controller
  - ATC Equipment
    - MSAW
    - Conflict Alert
    - OEDP

Resolutory Action

- Controller
  - Intervened
  - Issued New Clearances
  - Declared Emergency
  - Ordered Expedited Man.
  - Gave DF Steer
  - Activated Crash Alert
  - Separated Traffic
  - Provided Flight Assist
  - Issued Advisory
  - Issued Alert
- Aircraft
  - Automation Overrode Flt Crew
  - Equip. Prob. Dissipated
- None Taken
  - Unable
  - Anomaly Accepted
  - Detected After-the-Fact
  - Insufficient Time

Resolutory Action (cont'd)

- Flight Crew
  - Avoid-Evas Action
  - Exec. GAR or Missed Apch
  - Regained Acft Control
  - Overcame Equip Problem
  - Aborted Tkof
  - Became Reoriented
  - Ret. Original Clrnc/Course
  - Exec. Lost Com Procedure
  - Declared Emergency
  - Perf. Expedited Maneuver
  - PNF Interv/Seized Controls
  - PNF Interv/Other
  - Exerc. of Command Autho.
  - Prepared for Ditching
  - Executed a 180
  - Executed a 360
  - Dumped Fuel
  - Man. Out Penetrated Airsp
  - Man. Out Adverse Env
  - Abandoned Apch
  - Returned to Land
  - Diverted to Alternate
  - Forced Landing
  - Landed Off Arpt
  - Ordered Evacuation
  - Precautionary Landing
  - Evacuated (Aircraft)
  - Landed as Precaution
  - Diverted to Another Airport
  - Returned to Assigned Airspace
  - Returned to Assigned Altitude
  - Landed in Emergency Condition
  - Overrode Automation
  - Fire Extinguished

Other

Record Control
Accession Number
Coding Form
Coding Status
Multiple Report Flag
SGL
MUL
Analyst Graphic
Y
N
Source
NF
ANONOM
Reporter's ACN
Receipt Date
Reporter Graphics
Response to Reporter
Analyst Callback
Completed
Attempted
None

Air Traffic Incident
Air Traffic Incident
NMAC
Operational Error
Operational Deviation
Other ATC Handling
Pilot Deviation
Military Facility Deviation
Intra Facility Coordination Failure
Inter Facility Coordination Failure
Declared Emergency
FLT-ASSIST
SPILL-IN
SPILL-OUT

General Assesments					
Type of Event		Problem Areas			
	Unique Event		Performances		
	Recurrent Event			Flight Crew Human Performance	
	Unwanted Situation			ATC Human Performance	
Special Handling				Cabin Crew Human Performance	
	ROU			Maintenance Human Performance	
	ABR			Passenger Human Performance	
	OHN		Procedures-Policies		
	FYI			ATC	
	TEL			ARPT	
	RCC			ACR	
	MMW			MIL	
Primary Problem				Company	
	ATC Human Performance			FAA	
	Cabin Crew Human Performance		Documentation		
	Flight Crew Human Performance			Chart	
	Passenger Human Parformance			Publication	
	Aircraft			Regulation	
	ATC Facility		Design		
	Airport			Airspace Structure	
	Navigational Facility			Aircraft	
	Airspace Structure			Airport	
	Company		Equipment		
	FAA			ATC	
	Chart or Publication			NAVAID	
	Environmental Factor			Aircraft	
	Weather		Environmental Factors		
	Ambiguous			Weather	
Special Educational Value					IFE
	Y				Preoccupation
	N				Diversion
				Traffic	
Ranked Severity					Conflict
	Number (0 to 10)				Preoccupation

Situation	
GEN-SIT	FAA-POL
Acft Type or Class	See and Avoid
Aircraft Design	Fac Staffing
Equipment	Keep 'em High
Airframe	Enforcement
Engine	Flow Control
Chart	Noise Abatement
Publication	Non Radar Proc
An Intxn Name/Other Name	Criteria
Design	Wx Observ
Airspace	Separation
Route	Certification
Physical Facility	FLC
ATC	Ctlr
Arpt	Equipment
NAVAID	Oth Psn
TFC Performance Mix	Info Dissemination
Procedure or Policy	Charted Procedure
ATC Fac	Arr
Arpt	Dep
Company	Other
FAA	Twr-Enroute Ctlr
NAVAID	Equipment
FAR	Transponder
CPNY-POL	Oth
Alt Callout	Training
Alt Rptg	FLC
Crew Scheduling	Oth
Mntc Scheduling	Air Carrier Inspection
Push-Bk	Sterile Ckpt
Pwr-Bk	Emergency
Deicing	
Loading Procedure	
Info Dissemination	
Emergency	
Schedule Adherence	
Fuel Conservation	

Adverse Interactions	
Interpersonal	**Coord. within and between Facilities**
Intra-Ckpt	IntraFac
Inter-Ckpt	Twr
Intra-Fac	TRACON
Inter-Fac	ARTCC
Supvr-Ctrl	FSS
Ctrl-Oth	MilFac
FLC-ATC	InterFac
FLC-CAB	Twr-Twr
FLC-GND	Twr-TRACON
FLC-DISP	Twr-ARTCC
FLC-FSS	Twr-FSS
FLC-CENR	Twr-MilFac
FLC-CHKPLT	TRACON-TRACON
FLC-Oth	TRACON-ARTCC
Oth-Oth	TRACON-FSS
Labor Relations	TRACON-MilFac
	ARTCC-ARTCC
	ARTCC-FSS
	ARTCC-MilFac
	FSS-FSS
	FSS-MilFac
	MilFac-MilFac

Consequence
FAA/ATC
Investigated
Assigned or Threatened Penalties
Reviewed Incident with Flt Crew
Other
Physical Injury
Emotional Trauma
Acft Damaged
Tail Skid
Wing Tip
Undercarriage
Propeller
Tires
Fire
Company Review
Flight Canceled
Stranded
Maintenance Action
Violation Not Pursued

APPENDIX E: SITUATION AWARENESS

E-1. Introduction

In this report, we are concerned with failures of Situation Awareness, and it is important that this be differentiated from a similar term that is often used in related literature, Situation Assessment. Situation Assessment is used in contexts that are slow, deliberate, strategic, and search-oriented. Situation Awareness is used in the context of events, processes, and interactions that are fast, event-driven, and tactical or reactive.

Situation Assessment would be an appropriate term to use, for example, if a management team were considering a large, long-term investment in a foreign country, perhaps the construction of new manufacturing facilities. They would be well advised to gather data and to carry out systematic statistical projections related to such topics as employment patterns, vocational performance, education, technology development, drug abuse, disease, and security. They might even have an opportunity to employ sophisticated data-fusion methods and other problem-solving techniques to place their decisions and actions on a rational footing.

Situation Awareness (SA) is concerned with a completely different set of issues: the operational state of an expert human performer in a dynamic and potentially dangerous environment. In this report, we are considering pilots and air-traffic controllers operating in the global civil aviation environment. Other studies of SA have focused on challenging military operations, such as command and control in joint-operations combat. Still others have studied automobile drivers, anesthesiologists, space mission ground-controllers, and firefighters.

In Section 9 of this report, we proposed that Behavior in our definition of Scenario is always associated with loss of SA. To make progress on the analysis and measurement of Behavior, it is necessary to break SA down into more concrete and constructive components. Fortunately, we can draw on an extensive SA research literature. A number of previous studies have highlighted levels or stages of SA that are closely related to our list of discriminating components: Detection, Recognition, Interpretation, Comprehension, and Prediction (DRICP). Furthermore, we can draw on the extensive research literature in related domains of human factors, expert performance, and behavioral decision theory.

These components of SA can be further defined as follows:

> <u>Detection</u> is the act of discovering, discerning, or capturing attention as this is related to the existence, presence, or fact of an event. To be detected, event **E** must entail a change above threshold or a change from adaptation level, though **E** does not have to be assigned to a more abstract class or type. Balakrishnan (1998) provides a discussion of detection and the important related concept of *vigilance*. The vigilance-detection paradigm can be seen as the most elementary setting for Situation Awareness in which adequate performance is defined simply as noticing and responding to changes from baseline stimulation. (We note that *simple* does not mean *easy*—pure vigilance tasks are notoriously difficult and error-prone.)

Recognition is the act of relating a detected event **E** to a class or type of event that has been perceived before. Event **E** can be assigned to an event type when it is perceived as a recurrence of something experienced previously. Richman et al. (1996) discuss the central importance of recognition in expert performance. Expertise, in general, and expert-level Situation Awareness, in particular, depend on the acquisition of reliable and nearly automatic domain-specific skills of recognition.

Interpretation is the act of relating a specific event type to a network of actual and possible events of various other types. Event **E** cannot only be assigned a class, but it can also be related to other classes of event types within a conceptual structure. Ericsson and Kintsch (1991) have described these kinds of conceptual structures as *long-term working memory* (LTWM) and have presented experimental evidence for the central role of LTWM in experts' interpretation of domain-specific events.

Comprehension is the act of perceiving the significance of an event. Event **E** not only can be assigned a place within a logical or categorical paradigm, but can also be understood in terms of its role in a familiar temporal pattern of events. The pattern may enable an expert to infer past events that must have caused **E**, or future events that must follow from **E**, or concurrent events that must accompany **E**.

Prediction is the act of forecasting what will happen in the near future. Event **E** is understood as part of a predictable sequence, so that specific future events are expected based on the occurrence of **E**. In many domains, including aviation, experts typically stay "ahead of the curve" by actively predicting and preparing for plausible continuations.

The aim of this Appendix is to provide pointers into the research literature on SA, and to explain briefly how our technical approach, described in Section 9, relates to previous work. We will also be as explicit as possible about the boundary conditions and limitations of our approach, acknowledging that our simplifications will have to be corrected through future research.

E-2. Situation Awareness, Prediction, and Active Cognition

Humans are limited in the amount and kinds of information they can process, and in the speed with which they can process it. Highly trained professionals—pilots, physicians, firefighters—can get into situations in which the apparent information-processing requirements exceed human abilities. Yet experts usually perform reliably in these kinds of environments. How is this possible?

The lowest level of SA involves detecting and recognizing low-level attributes and dynamics of objects and events. The second level involves interpreting and comprehending the situation based on knowledge of significant, but more abstract, relations among the recognized elements. This level of interpretation and comprehension relates concrete objects and events to operational goals in ways that go beyond the data that are concretely available. The third level of prediction requires the ability to project the near-term course of events into the future. This highest level achieves closed-loop behavior via continuous perception of situation elements in relation to goals, threats, resources, actions, and consequences.

The key factor in many types of expert performance seems to be what Jones and Endsley (1996) have called "Level 3 SA," that is, prediction or mental projection, *"a very demanding task, which* *people generally perform poorly"* (p. 508). Expert knowledge can be defined, in large part, as a set of pre-compiled memory structures and specialized cognitive retrieval processes that, together, implement predictions of likely event-sequences, including adaptive responses. There is no mystery to the pre-compilation process: it is simply the outcome of many years of formal training and professional experience (Ericsson 1996, pp.10–11; Richman et al. 1996, pp. 172ff).

Prediction is the acid test of a scientific theory and is one of the major goals of applied science. Elaborate causal models and statistical methods are used to try to predict earthquakes, storms, climate change, and the time-course of epidemics. Prediction is also at the core of active learning strategies that are advocated by instructors to improve students' skills in reading, listening, mathematics, and test-taking. The ability to predict has obvious practical value in avoiding or mitigating the effects of unfavorable events, but it is also instrumental in effective cognitive performance. An orientation toward active prediction is the hallmark of cognitive engagement in an on-going task. Thus, prediction is a key component of all kinds of individual and collective expertise, and is perhaps the most important theoretical link between research on SA and research on learning and expertise.

E-3. Situation Awareness Research

Jeannot (2000) (see also van Gool et al. 2002) summarizes the Human Factors research on SA, emphasizing cognitive aspects such as mental models, long term memory, working memory, workload, and human-automation interaction, with special emphasis on the nature of SA in air traffic control (cf. Gronlund et al. 1998). He states:

> *"In many, if not all, of the controller cognitive models, maintaining Situation Awareness is the core sub-process, the basic background activity to air traffic control. The importance of "background activity" is recognized as critical by (controllers) themselves. They refer to this phenomenon as "having the picture." For controllers, "having the picture" is the first pre-requisite to handling their traffic.... "Losing the picture" is reported as one of the biggest risks for controllers, as it is the source of several risks: The controller*
>
> - *is no longer able to predict the evolution of the situation,*
> - *fails to detect early enough a problem or a conflict,*
> - *does not choose the optimum resolution,*
> - *and, in extreme cases, allows the creation of incidents or accidents."*

Domain-specific representations help to maintain SA via "cognitive economy" (Endsley 2000a). Only when information on position and altitude are insufficient for conflict detection will controllers look for other sources of information, and then they operate in predictive mode, anticipating the situation and working ahead. The more experienced the controller, the more selective his or her mental model becomes, even to the point of being "inaccurate" or "distorted"—but in ways that promote effective performance (Gronlund et al. 1998). Less experienced controllers have more concrete details available about traffic. They tend to "focus on every aircraft," whereas experts classify aircraft into two groups: "those requiring further analysis and those which can be separated safely immediately."

Patel et al. (1996, pp. 130ff.) provide an instructive discussion of active information-seeking in the context of medical expertise. They describe four stages of information processing called observations, findings, facets, and diagnosis. Observations are raw data at our detection/recognition (D/R) level. Findings are interpretations (I) of data, and facets are clusters of related findings. Diagnosis corresponds to our comprehension (C) level and constitutes the basis for predicting (P) the future (prognosis). Facets play an active role in organizing multiple competing interpretations, directing the search for additional data (findings) to resolve pending issues, and providing the building blocks for a satisfactory diagnosis. In-depth exploration of expert performance shows that even the cyclical model is an over-simplification (cf. Frederiksen and White 1990). The more highly skilled the expert performer, the more flexibly he or she moves among different knowledge representations and different levels of processing.

Different levels of proactive engagement in the dynamic control task characterize different levels of expertise. Cognitive engagement, prediction, and effective control are interrelated. This is one of the reasons why automation can sometimes undermine SA, producing

- loss of vigilance
- increase in complacency
- change from active to passive processing
- loss of or a change in the type of feedback.

Automation can also become the object of SA itself, in that more experienced operators develop skill in predicting the future behavior of automated systems (Jodlowski et al. 2002). Operators' SA regarding automated systems is in turn influenced both by training (Endsley and Robertson 2000) and by display design (Kelley 2002). Understanding automation can be defined, in part, as the avoidance of "automation surprises." Avoiding surprise is the same as being able to predict what will happen next if a certain input is provided to the automation (Woods et al. 1994). This human-automation interaction is further complicated by the fact that the automated system has its own SA of the state of its portion of the world.

In addition to automation effects, the management of SA in aviation and other environments can be complicated by factors such as distributed roles and responsibilities, which create the need for shared SA (among multiple human and non-human agents), and by mobility of the agents who must maintain this shared SA. Artman and Garbis (1998) and Stroeve et al. (2003) show how an initially safe situation can evolve into an unsafe one via divergent SA among the operators of the system. Johnston et al. (1997) emphasize the need for process analysis in addition to outcome measurement (i.e., the *why* in addition to the *what* in the terminology of this report). Individual and team processes interact in determining overall SA.

Taking an even broader perspective, Woods et al. (1994) (cf. Cook and Woods 1994) and Moray (1994) place SA in the context of human-systems analysis and research on human error as a systems problem. Cook and Woods point out the multifaceted nature of SA—control of attention, mental simulation, directed attention, contingency planning, mental bookkeeping. In general, any multitasking environment requires shifts of attention among different threads, and coordinating these shifts requires a coherent system-model or situation-model.

E-4. The Cyclic Nature of SA

In our simplified model of Behavior, we use the DRICP framework of SA as though Detection, Recognition, Interpretation, Comprehension, and Prediction occur in sequential order, each successive stage using the output of the preceding stage. However, as Carroll et al. (2001) document, citing Neisser (1976), human cognition is a cyclic process in which prediction facilitates comprehension and interpretation, and in which comprehensible and interpretable events are more easily detected and recognized than are unpredictable and incomprehensible events. In fact, Jones and Endsley (1996) point out that many Level 2 SA errors (for example, misinterpretation of landmarks) can be attributed to incorrect expectations (erroneous predictions), which then cause a persistent misrecognition and misinterpretation of perceptual data.

Figure E-1 from Neisser (1976), which we borrow from Carroll et al. (2001), illustrates the more complex model of active information seeking. Experts' skilled performance (Richman et al. 1996), as well as their characteristic susceptibility to certain kinds of errors (Cook and Woods 1994; Jones and Endsley 1996), can be best understood as a knowledge-driven, prediction-oriented cognitive process, not as a data-driven, passive, perceptual one.

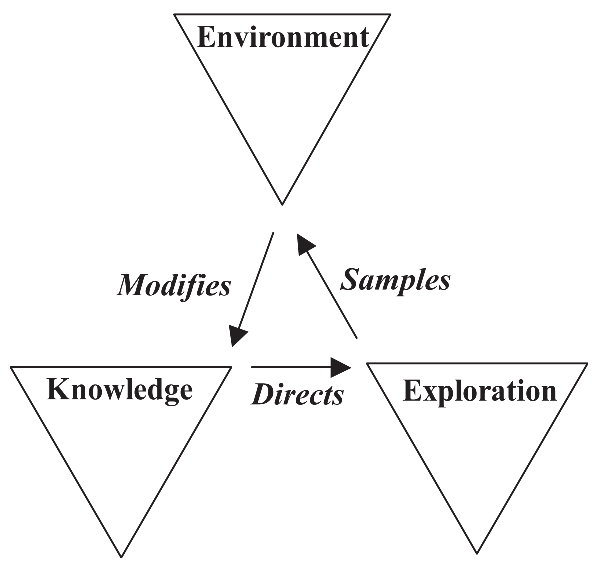

Figure E-1. The perception-action cycle (Neisser 1976).

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14. ABSTRACT
The objective of the Aviation System Monitoring and Modeling (ASMM) project of NASA's Aviation Safety and Security Program was to develop technologies that will enable proactive management of safety risk, which entails identifying the precursor events and conditions that foreshadow most accidents. This presents a particular challenge in the aviation system where people are key components and human error is frequently cited as a major contributing factor or cause of incidents and accidents. In the aviation "world", information about *what* happened can be extracted from quantitative data sources, but the experiential account of the incident reporter is the best available source of information about *why* an incident happened. This report describes a conceptual model and an approach to automated analyses of textual data sources for the subjective perspective of the reporter of the incident to aid in understanding why an incident occurred. It explores a first-generation process for routinely searching large databases of textual reports of aviation incident or accidents, and reliably analyzing them for causal factors of human behavior (the *why* of an incident).

We have defined a generic structure of information that is postulated to be a sound basis for defining similarities between aviation incidents. Based on this structure, we have introduced the simplifying structure, which we call the Scenario as a pragmatic guide for identifying similarities of what happened based on the objective parameters that define the Context and the Outcome of a Scenario.

We believe that it will be possible to design an automated analysis process guided by the structure of the Scenario that will aid aviation-safety experts to understand the systemic issues that are conducive to human error.

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