Looking Beyond the Cockpit: Human Computer Interaction in the Causal Complexes of Aviation Accidents

C.W. Johnson
Dept. of Computing Science,
University of Glasgow,
Glasgow, Scotland.
http://www.dcs.gla.ac.uk/~johnson
johnson@dcs.gla.ac.uk

ABSTRACT

Aviation mishaps stem from complex combinations of human error, managerial failure, design flaws, environmental and meteorological factors. Mackie [1] uses 'causal fields' to denote a subjective frame of reference that guides our search for particular causes. This helps to explain why many investigators focus on 'primary' forms of human computer interaction. There is a tendency to focus on the interaction between aircrew and onboard systems or between air traffic managers and their ground based software. In contrast, we argue that the causal field must be extended to cover secondary and tertiary problems in human computer interaction. Secondary failures indirectly contribute to adverse events and increase the likelihood of primary forms of 'error'. For instance, recent mishaps have been attributed to secondary problems in the software that general pilots use to plan their flights prior to departure. Tertiary usability problems stem from the difficulty of applying computer software to understand the events leading to an accident or incident. Tertiary software is not directly involved in the adverse event but is critical to reconstruct previous interaction. For instance, a number of recent investigations have been unable to probe flight data records to accurately identify the sequence of aircrew actions leading to an accident. This creates uncertainty about the role that human 'error' plays in the course of an adverse event. A detailed analysis of NTSB accident and incident reports involving human computer interaction failures between 1999 and 2004 is used to illustrate our argument.

Keywords

Accident analysis, HCI, ATM, Software Engineering.

INTRODUCTION

The usability problems that lead to accidents often form part of a more complex landscape of managerial and regulatory failure, of poor design and equipment malfunctions, of environmental conditions and of operational inadequacies Mackie [1] uses the term 'causal complex' to describe this landscape of failure. Although he was looking purely at the philosophy of causation, it is possible to apply his ideas to clarify some of the issues that complicate the investigation of aviation accidents and incidents. Each individual factor in a causal complex may be necessary for a mishap to occur but an adverse event will only occur if they happen in combination Several different causal complexes can lead to the same accident even though only one may actually have caused a particular failure. For instance, a navigational error might be compounded by poor weather or by inadequate air traffic management to result in a controlled flight into terrain. It is for this reason that most accident investigations consider alternate scenarios in order to learn as much as possible about the potential for future failures. In our example, an investigation might look at the potential impact of inadequate air traffic management even if the initial problem had led to a near miss rather than an adverse event [2].

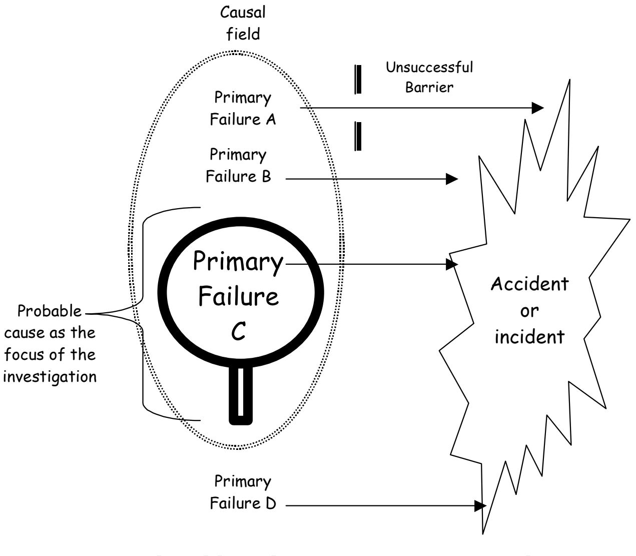

Figure 1: Causal Fields and Primary Interaction Failures

Mackie goes on to argue that we often make subjective decisions about those factors that we focus on within a causal complex. The term 'causal field' refers to those factors that an investigator considers relevant to a particular investigation. If a cause does not appear within this subjective frame of reference then it is unlikely that it will be identified. This philosophical work has empirical support from the findings of Lekberg who was able to show a strong correlation between the findings of accident investigators in the Swedish nuclear power industry and the subject of their first degree [3]. Human factors graduates were more likely to identify usability issues, process engineers were more likely to find problems in plant design and so on. Figure 1 provides an overview of Mackie's ideas and how they might relate to a Reason's view of accident investigation [4]. The causal field in this case concentrates on primary causes A, B and C. Within that, we can focus on particular issues that we raise to the status of 'probable causes'. This is illustrated by the magnifying glass. For example, an investigator might be predisposed to look at Crew Resource Management issues. This would be illustrated by the focus on primary failure C in Figure 1. However, the causal field may not encompass a sufficient set of conditions and in this case Primary failure D is not within the range of issues being considered by the investigator. For instance, if the investigation focuses on crew resource management issues then correspondingly fewer resources will be available to consider other issues. They might overlook the difficulty that the pilot had in changing transponder settings or in disengaging an autopilot.

THE NTSB DATASET

The following pages describe the results of an investigation into the NTSB incident and accident database covering adverse events from January 1999 to February 2004. The Aviation Accident Database contains data about civil aviation accidents and incidents within the United States. An accident is "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage." The incidents in the database do not involve the level of injury or damage but are defined to be "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations."

The NTSB database has more than 140,000 records. The start date of 1994 was chosen for this study because it marks the beginning of a policy to include free text narratives with each account of an incident or accident. This enables the use of free-text retrieval tools to look for patterns within the data set. [2] provides an overview of many of these systems. We exploited a form of conversational case based reasoning together with a local variant of a probabilistic information retrieval to extract the subset of incidents from the 140,000 records where human computer interaction contributed to the cause or course of a mishap. The retrieval engines enable analysts to ensure that this subset includes reports where synonyms and metonyms, such as 'software', 'code', 'application' or 'program', may have been used rather than literal syntactic matches. One limitation is that the size of the retrieved subset depends on the algorithm that is used to perform any match. The tighter the criterion used to associate similar terms then the smaller will be the subset. This makes it difficult to derive precise statistics from an analysis of this nature. A companion paper with Michael Holloway, NASA Langley, describes how such statistics can be obtained using exhaustive, independent manual review across NTSB accident reports [5]. In contrast, the remainder of this paper focuses on the results of applying retrieval software to identify patterns of human computer interaction in the NTSB databases.

PRIMARY INTERACTION FAILURES

Many of the incidents and accidents that were extracted by the software can be described as 'primary' interaction failures. By this we mean that they describe problems in the operation of flight deck automation or of air traffic management systems that would be very familiar to the audience of previous HCI in Aerospace conferences. This can be illustrated by the collision between a Gulfstream and a Beech C90 while both aircraft were on final approach to the same runway (NTSB Ref. LAX01FA018A). The pilot of the Beech aircraft was instructed by Air Traffic Management to change his transponder code to 1200 and contact the Tower at his destination. However, radar records show that the code was reset to 1206. After contacting the Tower, the pilot was given a new transponder code of 0220, however, the aircraft replied on 0226. This code had been pre-assigned to another sector. The Air Traffic Management software at the arrival Tower placed the Beech's radar target display in "suspend" status. The Beech's target remained on the radar display. However, the widget containing the aircraft type, identification and altitude was not displayed to the Air Traffic Managers until a minute before the collision when an alarm was sounded. Subsequent investigations by the NTSB revealed that the transponder controls were installed in the forward instrument panel. This was low and to the right side of the center avionics racking. It was, therefore, extremely difficult for the pilot to reach across and set the transponder while reading the displayed setting.

This incident illustrates the role of 'primary' interaction failures that directly lead to an adverse event. However, the collision was the result not simply of the interaction between the pilot and their transponder. It also stemmed from the difficulty that ATM staff had in observing the aircraft once an incorrect transponder setting had been selected. In other words, an interaction failure on the aircraft was exacerbated by further interaction problems with the ground-based systems. The controller's ability to detect the apparent anomaly was further impaired by other problems that did not directly relate to the radar software. The approach controller experienced frequent, intermittent, failures of his radio transmitter during the incident. He was, therefore, distracted by having to repeat a series of radio transmissions to other aircraft in the vicinity. The controller reported being 'very frustrated with both the radio (transmitter) and automation (data block) difficulties'. In other words, as Mackie suggests, the primary forms of interaction failure form part of a wider causal complex. Without this combination of interaction failures and external distractions through equipment failure then it might be argued that the accident would not have happened in the manner described above.

SECONDARY USABILITY PROBLEMS

Human computer interaction failures often form part of a more complex series of causes that are collectively sufficient for an incident or accident to occur [4]. The previous incident provides an example of a primary usability problem. The pilot's ability to set a correct transponder value was directly impaired by the location of the input device in relation to the associated display. However, many adverse events stem from 'second order' failures in human computer interaction. These describe usability problems that do not directly cause an adverse event but can help to create the conditions in which a mishap is more likely to occur.

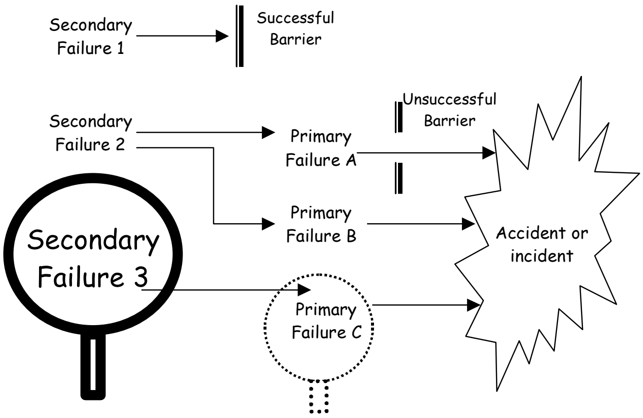

Figure 2: Causal Fields and Secondary Interaction Failures

Figure 2 provides an overview of secondary interaction failures. As can be seen, these usability problems contribute to primary failures. For instance, difficulty in calibrating on-board navigation systems, represented by secondary failure 2, can create a situation in which a pilot is likely to make a subsequent navigation error. This is illustrated by primary failure B in Figure 2. Alternatively, ground-based maintenance and inspection might identify the calibration error prior to flight. The successful barrier to secondary failure 1 in Figure 2 would illustrate this. An important aim of this paper is to extend the causal field of accident investigations to consider the role of usability problems in these secondary causes of adverse events. This is illustrated in Figure 2 by moving the magnifying glass to the left. The dotted elipse used to denote the causal field in Figure 1 could also be redrawn to show the extended scope of an investigation in this figure. Our emphasis on secondary usability problems is intended to guide the composition of a causal field, which Mackie argues can be a subjective and arbitrary process. These usability issues are an increasingly common factor in the assorted lists of 'contributory factors' that appear in accident reports. We would, therefore, argue that these secondary failures deserve greater and more sustained attention.

The primary causes of the Guam accident included the captain's failure to adequately brief and execute the non-precision approach. They also included the first officer and flight engineer's failure to effectively monitor the captain's execution of that approach. In contrast the secondary or contributory causes included the FAA's decision to authorize the inhibition of the Minimum Safe Altitude Warning system. This restricted the operators' uninhibited MSAW support to a radius between 54 and 55 nm. The inhibition was intended as a temporary solution to reduce "nuisance" warnings but significant impaired the Air traffic Managers' ability to use MSAW as an effective barrier against such adverse events. These secondary forms of human computer interaction already form part of the causal field that is typically considered after high-profile major accidents, such as Guam. However, they are less often considered in the aftermath of lower consequence and near-miss incidents within the NTSB database.

Report ANC01IA022 provides an example of secondary usability problems when it describes turbulence damage to a Being 747-422. The incident occurred inside the only Flight Information Region in the 'Pacific Theatre' not to provide Controller/Pilot Data Link Communications. This FAA system can be used to transmit clearances and weather data to oceanic flights that are equipped with an Aircraft Communications Addressing and Reporting System. In the aftermath of the incident, the aircraft operator argued that if the Air Traffic Management had provided these data link communications then the crew could have received and reacted to an earlier turbulence warning. Other centers had successfully used the system for providing these warnings and steps were in place to increase vertical separation should several turbulence warnings be issued on the same routing. The 'second order' nature of this incident is revealed by the reasons why data link communications were unavailable. Local Air Traffic Managers had attempted to introduce data link facilities. Subsequent investigations revealed that this had been 'curtailed because the software is not user friendly, requires substantial controller input for free text messaging, and is not as fast as voice communications'.

One reason for the prominent nature of second-order interaction problems is that pilots now draw upon a wide range of software applications to support their everyday activities. NTSB Report FTW02FA036 illustrates this. The pilot and three passengers of a Piper PA-31T1 twin-engine airplane were killed on impact with the ground. The probable cause of the accident was the pilot's decision to continue his approach under heavy fog in instrument meteorological conditions. However, this was the pilot's second flight using a new GPS installed on the aircraft and the pilot had been practicing at home using an emulator on his desktop PC. The NTSB examined the software but was unable to determine which approaches or navigation techniques the pilot had been practicing. Although the use of this software did not directly contribute to the accident, such systems can play an important secondary role in the causes of some adverse events. A recent study of military accidents has shown that the presence of desktop simulators can lead to overconfidence in an operator's ability to use navigational systems under eventual operating conditions [5].

The diverse nature of the software that contributes to secondary interaction problems can also be illustrated by NTSB report NYC00LA003. In this case, the passenger and commercial pilot of a Piper PA-60-700P were uninjured. The pilot attempted to land his aircraft on a runway that had been closed. He recalled that "... I was not able to see any of the construction due to the significant crown to the runway, so I began normal braking. Upon reaching the crown in the runway, I observed debris [on] the runway, and immediately applied maximum braking. The wheels locked up and it became apparent that the plane could not be stopped prior to reaching the debris....". A Notice To Airmen (NOTAM) had been issued. In the pilot's written statement, he described obtaining a weather briefing and reviewing NOTAMS before the flight using flight planning software. However, he did not recall seeing any warning for the closure of the runway at his intended destination. It is instructive that the NTSB report did not probe into the reasons why the pilot did not notice any warning on the flight planning software. It is, therefore, impossible to determine whether this oversight was due to a perceptual error, to poor interface design or to a factual omission. Such ambiguity again illustrates the importance of focusing additional resources to improve our understanding of secondary usability problems. Unless these issues are treated more seriously then there is a danger that we will continue to witness similar incidents in the future.

Our analysis of the NTSB database identified several different types of 'second-order' usability problem. For example, more direct forms of human 'error' are likely when on-board software fails to operate in the manner intended. Such malfunctions need not directly lead to an adverse event especially if other barriers are in place to prevent an accident. However, they can create the context in which more direct forms of error are more likely to occur. This can be illustrated by a collision involving two F-16 fighters and a Cessna 172 (NTSB Ref. MIA01FA028A). One of the F16's navigation systems began to show that the aircraft was several miles away from its actual location. The pilot did not notice the problem partly because he was preoccupied with trying to find the start of his training route using visual observations. These observations did not match his expectations because he was several miles off course. The two problems formed a 'deadly embrace'. He did not spot the malfunction because he was preoccupied with starting the training run. Conversely, he could not identify the start of the training run because of the navigational malfunction. Meanwhile the F16s began to descend into Class C airspace.

While this was going on, the Cessna 172 took off and entered the sector being managed by a trainee controller. An adjacent control center asked the local center for the altitude of the F-16s. The local controller was not in contact with the military aircraft but was able to locate the flight on his radar display. Subsequent examination of the system logs showed that the local controller's intruder conflict detection software had noted a conflict between the flight lead F16 and the Cessna. This would have generated an aural conflict alert in the Air Traffic Management that is recorded as having been activated ten times in under a minute. The controller who was being trained later stated that he heard an alarm, but could not remember where it was. The training officer did not recall the conflict alert; he argued that these were a frequent occurrence and that there were many 'false alarms'. In consequence, neither of the managers issued a conflict alert to the pilots. No alert was generated between the F-16 and the Cessna because the conflict alert system required both aircraft to be operating their transponders. However, the F-16's transponder had been placed into a standby mode. The controller under instruction did eventually alert the pilot of the lead F16 that he had traffic on his left side. The pilot did not respond to the warning. The controllers were unsure about the position of the second F-16 and it was this plane that eventually collided with the Cessna. The pilot of the lead F16 stated that he not detect any navigational problems on the return flight to their base after the accident; "I had no suspicion at all that there was a navigation system problem."

It can be argued that the problems in entering the navigational information were a primary cause of the collision. However, the NTSB investigation argued that the pilot's interaction with their on-board computers was a secondary cause. As mentioned, second order usability problems create the context in which an accident or incident is more likely but do not themselves trigger that incident. The NTSB argued that the primary cause was the pilot's failure to maintain adequate visual lookout while maneuvering. As we have seen, however, this is a very fine distinction given that the pilot's visual resources were preoccupied with finding the start of their training route and that this, in turn, was compounded by their failure to detect the navigational error. The meta-level point here is that any attempt to focus or direct research within human-computer interaction in aerospace must take into account the complex nature of many real-life incidents and accidents. Cockpit design cannot be considered in isolation from the more complex tasks that pilots are expected to perform. Aircrews are typically very good at adapting to bad interfaces. Problems, typically, occur when these design problems are compounded by other 'primary' or 'catalytic' causes of incidents and accidents, including competing demands on finite perceptual and cognitive resources. The subsequent investigation by the aircraft manufacturer concluded that: "A position error of approximately 9-11 nm was entered into the navigation system at some time on the mishap flight prior to the video recording. It can not be determined from the data what caused this position error." This is similar to the previous incident involving the use of flight planning software. In neither case was a subsequent investigation able to identify the precise usability problems that led to the human 'error'. In the former case, readers cannot determine whey a pilot failed to observe the NOTAM informing them about the closed runway. In this incident, we have no idea why the positional error was entered into the system. These represent missed opportunities to learn from the secondary usability problems that contribute to the causal complexes of incidents and accidents.

Previous sections have argued that human computer interaction, typically, forms a small component of the wider causal field that is identified in the aftermath of most accidents and incidents. Usability issues play a secondary role to equipment failure, to procedural violations or meteorological causes. As a result human computer interaction can be classified as a contributory factor that deserves less attention when investigators draft potential recommendations. It is important to emphasize that many of these interaction problems are themselves the result of earlier failures, for example in the design, acquisition and testing of system components. The lower priority that is often associated with contributory factors often means that few of these issues are ever considered in accident and incident reports. It is rare for an investigation to result in a usability study, although there are some exceptions [4].

The increasing complexity and integration of cockpit avionics can also prevent investigators from identifying the precise manner in which systems might have contributed to interaction problems. For instance, the crew of a passenger aircraft completed their taxi-out and pre-departure checklist without problem (NTSB Ref. FTW02LA198). They then set V1 to 139 knots and Vr to approximately 143 knots in the flight management system. Both crewmembers recalled that their primary flight display showed the correct V-speeds. The pilot flying the aircraft then entered the V2 speed into the flight control computer and entered 250 knots for the extended speed to 10,000 feet. The other crewmember did not recall being distracted during these tasks.

The plane was cleared for departure and the pilot flying the aircraft applied standard take-off power. His colleague called out '80 knots' and the fight instruments were crosschecked to ensure they both confirmed this speed had been reached according to the primary flight displays. The pilot not flying then checked the engine diagnostic page to observe vibrations with the number two engine. When he looked back at the primary flight display, he recalled that the V-speeds were not being displayed and that V2 had reset to 100 knots. He nevertheless called "V1 rotate," and the pilot flying attempted to establish a pitch of around twelve degrees. The airplane failed to climb or accelerate as expected. The pilot not flying realized that the airspeed was approximately 120-125 knots, which was well below V2. He, therefore, called for the nose to be lowered. The pilot decided to reject the take-off and pulled the throttles to idle. The flight control computer automatically applied maximum auto brakes, the airplane slowed, and was taxied off the runway at high-speed.

The manufacturers examined the Flight Control Computers Fault Logs to determine what might have caused these apparent problems with the flight management system. The logs revealed that the selected calibrated airspeed was 100 knots, rotation was attempted at 107 knots and a tail strike occurred at 119 knots. The NTSB investigators failed to identify either a probable cause or a contributory factor in this incident. There was no evidence of a system failure. Although the number 1 Flight Control Unit was found to have a fault, the manufacturer's representative argued that it would have had "no effect on this event". The operator's representative argued, "test results for the Flight Control Computer, Flight Management Computer, Flight Warning Computer, Electronic Centralized Aircraft Monitoring Computer, Flight Augmentation Computer, and Signal Generator Unit found no faults. Further, the Flight Control Unit (the part of the Flight Control Computer where pilot's enter target airspeeds and altitudes on the glareshield) did not log any faults and tested ok."

Human error was suspected, however, both crewmembers had considerable experience of these operations. Both had obtained sufficient rest in the 72 hours before the flight. The pilot flying had never previously operated a large transport aircraft at speeds well below V2 before. This example again illustrates the way in which interaction problems may be suspected but relatively few resources are allocated to improve our understanding of what those problems might be. If we assume that human error might have played a part in this incident then we must accept that an experienced and well-rested flight crew could make a potentially catastrophic mistake even when following approved SOPs. The lack of any clear conclusions here makes it difficult for the readers of the report to determine an appropriate response to this incident. This report is typical of many where secondary problems in human computer interaction are left unexplored and unexplained.

Uncertainty about the causes of secondary interaction problems can be compounded by the problems of underreporting. Some of the incidents in the NTSB dataset reveal how little we actually know about the everyday usability issues that routinely go unreported because pilots adopt 'coping strategies'. They adjust their behavior and will work around poorly designed systems. One consequence of this is that we never hear about incidents that might otherwise prompt intervention by investigatory and regulatory organizations. This is illustrated by sections of the NTSB report reference ATL02LA013. The incident began with a reported failure of the autopilot trim during takeoff. The student pilot tried but failed to disconnect the autopilot with the button on the control yoke. The student lost control and the aircraft began to porpoise on landing. The main focus of the investigation was on a student's lack of autopilot training. She stated that she had not received any training on the autopilot system. As in previous incidents, the precise reasons for the initial failure were undetermined. The manufacturer tested the autopilot in the presence of the FAA and the NTSB investigator-in-charge but no abnormalities were noted. However, it was revealed that the autopilot could be inadvertently engaged by pressing the heading, altitude, or autopilot button. The aircraft and autopilot manufacturers, therefore, incorporated an autopilot software and checklist change into a service bulletin. This incident reveals primary and secondary problems in human computer interaction. There was a primary failure to control the landing. This 'error' was made likely by a secondary failure to disconnect the autopilot that was, in turn, made more likely by a lack of training on how to control this software. The incident also provided insights that were apparently unrelated to the adverse outcome, in this case the manufacturers addressed the problems of inadvertent activation.

This report also illustrates the way in which underreporting can prevent effective action from being taken when secondary failures do not result in an adverse event. During this investigation, it was found that there had been similar problems with the aircraft in the preceding months. One pilot stated that he noticed the trim tab turning itself up and down as he was taxing onto the runway. He showed it to his instructor and he was instructed to disengage the autopilot by pressing the button on the yoke. The autopilot did not disengage. He reached out and disengaged it using the autopilot button on the console. Another pilot stated that while on final approach he tried to disengage the autopilot by pushing the red button on the yoke. Again it would not disengage but he nevertheless managed to complete a successful landing. Neither pilot had reported the discrepancy to the operator. Not only must we increase investigators' awareness of secondary usability problems. Such events illustrate the important of making pilots and other personnel aware of the dangers that can arise when such incidents go unreported.

Tertiary Usability Problems

First order usability problems lead directly to an incident or accident. They are cited as the probable cause of an adverse event when, for instance, a pilot enters an incorrect waypoint and flies directly into terrain. Such primary failures are rare [4]. Most usability problems have secondary effects. For example, entering incorrect navigational information can prevent aircrew from making the direct visual observations that are ultimately identified as the probable cause of the incident. As a result, most usability problems are classified as 'contributory factors' rather than probable causes in accident reports. The increasing prominence of these secondary factors in incident and accident reports suggests that more attention should be played to their role in the causal fields that guide incident investigations.

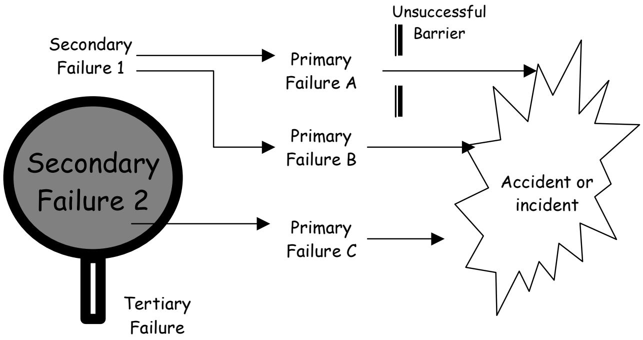

Figure 3: Causal Fields and Tertiary Interaction Failures

Figure 3 illustrates a final form of usability problem that complicates the analysis of aviation accidents. Tertiary problems complicate the investigators' use of automated flight recorders to reconstruct the events leading to an incident or accident. In this case, the systems that are intended to help us focus on interaction problems fail to provide vital information. In Figure 3, this is illustrated by the darkened magnifying glass. For example, the pilots of a Dassault DA-900 decided to continue with an approach in spite of a strong tail wind and insufficient distance on the runway to complete the proposed landing (NTSB Ref. NYC00FA092). Investigators argued that the incident was caused by the flight crew's inadequate coordination and improper weather evaluation. Other causal factors included the captain's decision to continue the approach and his failure to obtain the proper touch down point on the runway.

The readout of the flight data recorder was accomplished using NTSB equipment. However, the entire trace produced a series of null values. No synchronization words were recorded. The manufacturer simulated the airplane's Flight Data Recorder on a test bed. The intention was to replicate the extracted file. Various scenarios failed to record the observed sequence of null values. The manufacturer determined, from the test, that the Flight Data Acquisition Unit might have been the source for the problem. This should have resulted in the illumination of the "FDR Fail" light in the cockpit. Using a test bench, the Flight Data Acquisition Unit manufacturer was able to determine that its processor had failed. This report provides an example of a third-order human computer interaction problem. The aircrew's failure to spot the Flight Data Acquisition Unit warning did not directly cause the accident. Nor did it create a situation in which an incident was more likely to occur. It did, however, act as a potential barrier for investigators who must determine the causes of an adverse event and then reduce the likelihood or consequences of any future recurrence.

As mentioned, the NTSB dataset revealed a cluster of incidents where the human computer interaction problems related not simply to cockpit or air traffic management systems. In contrast, they related to the applications that investigators use to understand events leading to a mishap. For instance, Report LAX00FA041 describes how an NTSB laboratory engineer attempted to read the information from a flight data recorder without removing the vicalloy recording medium. After noticing that the first subframe on each frame contained erroneous data, the engineer removed the tape and transferred it to transcription equipment. As in previous incidents, the engineer was unable to determine the cause of the problems with the data recorder. The critical nature of such data sources in reconstructing the sequences of interaction between flight crew and their automated systems reinforces the need to support such third order forms of human computer interaction. Although the investigator and laboratory engineer may be a long way removed from the scene of an accident or incident, we must rely on their observations to guide any subsequent intervention. Many researchers have an unrealistic optimism about the infallibility of flight data recorders that is not warranted by many of the incidents in our survey.

CONCLUSIONS

Previous sections have described how human computer interaction, typically, only forms a very small part of the 'causal field' that is identified in most accident and incident reports. Usability issues often play a secondary role in mishaps that are triggered by other causes, such as major equipment failure. As a result they can be classified as contributory factors that deserve less attention when investigators draft potential recommendations. In contrast, we have argued that mishap investigations must be extended to cover both secondary and tertiary problems in human computer interaction. Secondary problems indirectly contribute to adverse events. For instance, a number of recent mishaps have been attributed to problems in the software that general aviation pilots use to plan their flights prior to departure. Tertiary usability problems stem from the difficulty of applying computer software to understand the events leading to an accident or incident. Very little attention has been paid to these broader forms of human computer interaction. However, unless these issues are considered then there is little chance that we will gain a full understanding of the causes and context of primary interaction failures.

REFERENCES

1. J.L Mackie, (1993), Causation and conditions. In E. Sosa and M. Tooley 9eds.), Causation and Conditions, pages 33-56. Oxford University Press, Oxford, 1993.
2. C.W. Johnson, (2003), A Handbook of Incident and Accident Reporting, Glasgow University Press. Available on http://www.dcs.gla.ac.uk/~johnson/book
3. A.K. Lekberg. (1997), Different approaches to incident investigation: How the analyst makes a difference. In S. Smith and B. Lewis, editors, Proceedings of the 15th International Systems Safety Conference, pages 178{193, Unionville, VA, United States of America, 1997. Systems Safety Society.
4. J. Reason. (1997) Managing the Risks of Organizational Accidents. Ashgate Publishing, Aldershot,
5. C.W. Johnson, (2004), The Role of Night Vision Equipment in Military Incidents and Accidents. Technical Report submitted to Human Error, Safety and Systems Development, Toulouse, France.
6. C.W. Johnson and C.M. Holoway (2004), An Independent Expert Review of Causal and Contributory Factors in Canadian TSB Aviation Data 1996-2004. Submitted to HCI in Aerospace 2004.