Responding to Uncertainty on Approach in Hazardous Situations

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Abstract— **The management of uncertainty is a recurring theme in Air Traffic Management and in understanding the way operators accomplish their objectives in a complex, dynamic environment. The current study reports on the verbal communication processes of crews and controllers during the approach flight phase and faced by uncertain situations. A conversation analysis of six (6) accident transcripts was conducted, with dynamic environmental interactions as a complexity factor. The results are presented in the forms of correlations among factor pairs. Results indicate a large variation (5.46%-32.09%) of the detection of uncertainty across accidents. Air Traffic Control and Ground Services (ATC/Ground) rarely initiated problem-solving exchanges (7%) in uncertain situations, as compared to crews (93%). Crews initiated 80.6% of problem-solving exchanges based on the direct perception of environmental cues while ATC/Ground initiated 19.4% of exchanges based only on indirect cues. Finally, our results indicate that ATC/Ground account for 68.8% of overlapping and 88.9% of compounded verbal exchanges. We conclude that the response to uncertain situations arising from hazardous conditions seems to correlate with a management by crews on approach. The effective transfer of uncertainty cues between crews and controllers does not appear to correlate with collaborative and communicative practices.**

Keywords- Uncertainty; Adaptation; Environmental Hazards; Verbal; Conversation Analysis; Air Traffic Management.

I. Introduction

The ability to detect and adapt effectively to uncertainty in naturalistic situations is a crucial requirement for preserving the control of a system faced by dynamically changing environmental factors. In a divided labour setting, the detection and reaction to uncertain situations by an operator, often involves the heedful interrelating of one's own work to that of others [1]. This interaction between system entities occurs differently, depending on the work setting where they are placed – thus, operators working within a proximal physical space can use the full variety of verbal and non-verbal communicative abilities. Conversely, operators located far from each other can communicate verbally through technology, although with perceptually impoverished cues.

Verbal communication between pilots and controllers during the approach flight phase is one of the main perceptual means of interaction. The verbal exchanges consist of task-related information accompanied by coordinative cues to allow both teams to work synchronously [2]. In uncertain situations, the effectiveness of verbal interactions can be negatively affected due to the quality of the radio-link, the informational efficiency of the message and also by the informative effectiveness of the message. While the quality and efficiency of exchanges have been addressed by much research (cf. [3-10]) the role of effective verbal interactions on approach needs to be clarified.

For verbal information to be effective, it needs to relate succinctly with its context of use [11]. Thus, an effective message does not supply more or less information that is required and subsequently, the message sender needs to understand the context within which the information will be integrated. The current study investigates the collaborative effectiveness of crews and controllers by analysing the messages they address to each other during uncertain situations. Due to the wide variety of factors which can lead to uncertain situations, we chose to focus on some specific interactions with the environment – the relationship of weather to other approach factors such as runway choices, checklist executions and plan changes are of interest.

II. Hazardous Situations in ATM

The qualification of a situation as being hazardous is considered from two perspectives, namely in hindsight and in foresight. Accidents and incidents are an undesirable state of the ATM system and indicate with a high degree of certainty that a hazardous situation might have been present. In retrospect, the contributory causes of occurrences (accident and/or incident) can be determined by measuring the performance variability of different parts of the system with respect to accepted safety standards. However, the analysis of occurrences tends to provide a picture of performance variations which can readily be deemed hazardous even though the same performances also contribute to effective ATM operations, on a routine basis [12].

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In foresight, the determination of a situation as being hazardous cannot be objectively defined using a fixed set of criteria. Risk analysis addresses this problem by mapping known system interactions into complex linear models. However, linear models such as event and fault-tree analysis cannot represent factorial interactions which do not exist a-priori [12]. Therefore, more powerful models which allow dynamic relationships to be represented have been proposed such as the Functional Resonance Accident Model (FRAM) [13]. According to the FRAM safety hazards may arise when separate functions which are designed to tolerate a range of performances, resonate with each other. This interference might be gradual (such as the slow erosion of approach procedures), or abrupt (for instance, a dynamic wind direction change late on approach) but can potentially lead to incidents and accidents.

III. Managing Uncertainty on Approach

Two main ways by which organisations which face significant safety-risks handle uncertainty, are described [14]. The first is to try and minimise uncertainty at work and the second tries to teach workers to respond effectively to uncertain situations when they arise. These approaches have very different implications.

A minimisation of uncertainty approach mainly deals with the adequate positioning of safety barriers within the system. Highly procedural work settings such as ATC and piloting consist of an enormous amount of rules, regulations and physical constraints to dampen the variety of the complex environment such that control is preserved over flight operations. Pilots and controllers are formally trained to comply with constraints, primarily as a means of preserving the predictability of the system, and hence its safety. In the event of unexpected situations, pilots are instructed to execute the appropriate remedial procedures, as and if provided in their operations manuals. It is to be noted that such procedures mainly relate to mechanical failures and not psychological issues occurring in the dynamics of the group. It should also be noted that the execution of a procedure entails first of all, an adequate diagnosis which is carried out by the crew members. Hence, given the wrong diagnosis, not only will the remedial measures prove to be inadequate, but the ensuing effects of those measures will be imputable to the captain.

Despite the large amounts of constraints presented by the minimisation of uncertainty approach, expert controller and pilot teams often deviate from procedures as a means of achieving expected performances [15]. The need to remain flexible to an uncertain environment forms the core of the second approach: adaptation to uncertainty. This approach levies some of the system control from the blunt end of organisation and relies on the local competences of operators at the sharp end, to cope with uncertainty. This approach is core to the socio-technical design principle of handling variances at their source (cf. [16]). Figure 1 shows some basic principles for managing uncertainty in organisations. Instead of a choice between the two approaches for managing uncertainty, a compromise or balance forms the target. The feed-forward control approach and the feedback control approach each have their own advantages and disadvantages which need to be addressed by organisations that wish to remain adaptive at the sharp end although retaining enough control at the blunt end [17].

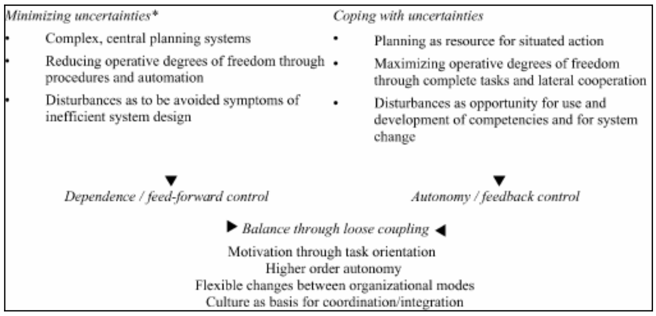

Figure 1. Basic Principles of Uncertainty Management Arising from Organisational Design [17].

IV. Analysis of Verbal Interactions

During the approach flight phase in ATM, the verbal means of communication between crews and controllers is primarily used for co-ordinating actions. The informational structure of verbal exchanges needs to abide by standard aviation phraseology, although exceptions are tolerated [18]. The radio communication protocol is sequential in nature between any two operators, because radio communications are half-duplex – simultaneous voices can still be heard on the radio channel to produce the commonly called 'party-line' effect. Verbal exchanges can also be seen as sequential according to turn-taking models of speech – such models regard simultaneous exchanges as a communication breakdown which informs us on the situation at a moment in time [19].

Conversation Analysis (CA) [20-24] builds upon the rich work in Speech Acts [25] to provide a theoretical framework for analysing verbal interactions. CA considers a number of properties of verbal exchanges to hold tacit information about a scenario [26]. The temporal delays which underlie communication handovers among humans, the stutters which are believed to underlie an uncertain mental state and the frequent verbal repetitions which might denote a sense of urgency are some of the verbal properties analysed. The methodology claims to provide detailed analytical accounts, while preserving the context of the verbal data [24, 27].

Nevile describes verbal mechanisms which are frequently recurrent across incident/accident investigation reports as providing a useful starting point for analysing the activity patterns of air-ground teams. Nevile and Dekker both propose a detailed CA of Cockpit Voice Recorder (CVR) data as a means of understanding the activities of crews and controllers [27, 28]. The limitation of this approach is seen to arise from the provision of original CVR data such that rich sound cues can be transcribed. Indeed, most CVR transcripts exclude subtle cues such as the tonal variations and word accents in sentences which conversation analysts treat as semantically significant.

V. Methodology

A Conversation Analysis of CVR and investigative data from six (6) aviation accidents was performed. Two aviation

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incident and accident databases were chosen as a means of providing our data – the similarity of reporting formats justified this choice. The databases are the National Transportation Safety Board (NTSB), in the United States and the Bureau d'Enquêtes et d'Analyses (BEA), in France. Table I shows the selected sample of accidents.

TABLE I. SELECTED SAMPLED OF ACCIDENT REPORTS

Case Name	Location	Description
5N-MAS	Istres, FR	Loss of engines during flight
F-GRJS	Guipavas, FR	Impact with ground obstacles after landing
N215AA	Arkansas, US	Runway overrun during landing
N497FE	Florida, US	Collision with trees on final approach
N963AS	California, US	Loss of control and impact with Pacific Ocean
N999UA	Colorado, US	Uncontrolled descent and collision with terrain

Although CA explicitly renders the cues which are obfuscated in verbal data, its ability to generate thematic patterns is limited. In this study, conventional qualitative analysis techniques were use to regroup semantically relevant information. Table II shows the qualitative codes used in this study and the categories under which they were regrouped. The references obtained for each code are then counted and a correlation table drawn to build the relationships among co-incidental factors. For instance, references to the 'Interruption' category and the 'Information Repair' category might correlate to reveal that further causal investigation of the factor pairs is required.

TABLE II. CODING CATEGORIES, CODES AND DESCRIPTIONS

Code Category	Code	Description
Familiarity	Colloquialism, Exclamation, Expletive.	The level of familiarity expressed by crews and controller.
Cue Perception	Direct Perception Indirect Perception	Environmental Perception. Direct perception is visual. Indirect perception is relayed verbally through ATIS, ATC or cockpit member.
Information Repair	Compounded Exchange Repeated Exchange	Compounded are multiple items of information stringed into one exchange, before turn is over. Repeated are requests which have been announced before.
Interruption	Overridden Subject Subverted Subject Overlapping Turn	Overridden is when the subject of an exchange is completely changed. Subverted is when the original turn subject is lost at the end of the conversation. Overlap is when there is less than a second of delay between messages.
Non-Verbal Feedback	Effort Laughter Mechanical	Efforts are cued by heavy breathing noises on the microphone. Laughter is cued by 'haha' variants and 'chuckles' on the microphone. Mechanical feedback are alarms, alerts, clicks, beeps, and any other sound referred as emanating from machines.
Problem Initiator	Pilot Flying (PF) Pilot Non Flying (PNF) ATC/Ground	Person initiating a problem-solving exchange. Machine initiations are situations where alarms initiate a reaction of the persons' exchanges.
Uncertainty	Level of Uncertainty	Level of uncertainty are cued by hesitation marks such as 'err', 'hum' and explicit remarks such as 'I don't know', 'I'm not sure', 'Maybe', etc.

VI. RESULTS

The 6 qualitatively analysed sources generated a total of 1407 coding references. A correlation table was drawn using the initial codes from Table 2 to determine the relationship between different factors. Factor combinations are presented below, with examples of how and when they occurred.

A. Problem Initiator

The system entity initiating a turn can take the form of either a human or a machine – in certain situations, an alarm initiates a problem-solving exchange among the Pilot Flying (PF), Pilot Non Flying (PNF) and controller. In the sources analysed, the PF was seen to initiate the most problem-solving exchanges (38.4%). PNF initiated about 26.1% while ATC and ground operations about 35.5%. Machine initiated exchanges were the least at about 3%. Table III shows the results in summed form.

TABLE III. PARTY INITIATING A PROBLEM-SOLVING EXCHANGE

Party Initiating an Exchange	Sum
Pilot Flying (PF)	78
Pilot Non-Flying (PNF)	53
Air Traffic Control (ATC) / Ground Services	66
Machine	6

The larger number of exchanges relating to problem-solving in the cockpit (67.5%) is an important relationship although the nature of CVR presents more data concerning cockpit conversations than ground exchanges. Further interactions are analysed below to understand problem-solving exchanges and uncertainty management.

B. Uncertainty and Problem Initiator

Verbal exchanges denoting a sense of uncertainty were present across all sources for a total of 258 references. The percentage of uncertainty references was not homogeneous across sources, as shown in Table IV and denotes some fundamental differences in the development and perception of hazardous situations.

TABLE IV. UNCERTAINTY REFERENCES IN SOURCES

Source	Sum	%
N963AS	71	32.09
F-GRJS	23	5.46
N215AA	52	26.86
N999UA	10	6.56
N497FE	28	24.52
5N-MAS	74	10.80

The lowest modes were for F-GRJS (Impact with ground obstacles), at only 5.46% and N999UA (Uncontrolled descent),

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at 6.56% of problem initiations with uncertainty. Both of these accidents are characterised by a relatively quiet and non-eventful series of verbal exchanges, until the last minute before the impact.

TABLE V. UNCERTAINTY AND PROBLEM INITIATION

Party Initiating an Exchange	Sum
Pilot Flying (PF)	14
Pilot Non-Flying (PNF)	26
Air Traffic Control (ATC) / Ground Services	3

To understand the role played by operators during uncertain situations, we cross-tabulated the uncertainty information from the sources with the person initiating a problem-exchange. Table V shows the sum of references when an operator was initiating a problem solving exchange and a situation was deemed uncertain. In uncertain situations, the PNF was seen to initiate the majority of problem-solving exchange (60.5%); the PF initiated 32.6% of exchanges. Finally, the controller initiated only about 7% of exchanges during uncertain situations – in many references, these problem-solving attempts by the controller occurred after the crew had displayed a level of uncertainty, verbally.

C. *Familiarity and Problem Initiator*

TABLE VI. FAMILIARITY AND PROBLEM INITIATOR

Party Initiating an Exchange	Sum
Pilot Flying (PF)	11
Pilot Non-Flying (PNF)	11
Air Traffic Control (ATC) or Ground Services	1

The inter-personal relationship among team members plays a significant role in determining information flows namely during hazardous situations. We observed an equal number of problem-solving exchanges (47.8%) for both the PF and PNF, while addressing each other using familiar terms. Air to Ground displays of familiarity only occurred once throughout all the accidents analysed.

D. *Problem Initiator and Cue Perception*

TABLE VII. PROBLEM INITIATOR AND ENVIRONMENT CUE

Party Initiating an Exchange	Direct Cue	Indirect Cue
Pilot Flying (PF)	6	6
Pilot Non-Flying (PNF)	11	2
Air Traffic Control (ATC) / Ground Services	0	6

The perception of visual cues is often a verbally described event, namely when the crew is engaged in problem-solving activities. We observed that the PF and PNF combined, perceived about 80.6% of all cues which relate to problem-solving exchanges. Comparatively, ATC and ground services perceived about 19.4% of cues relating to problem-solving – all cues found for controllers were indirect, given their location within approach centres, and in indirect contact with the external environment.

E. *Compounded Exchange and Problem Initiator*

TABLE VIII. COMPOUNDED EXCHANGE AND PROBLEM INITIATOR

Party Initiating an Exchange	Sum
Pilot Flying (PF)	0
Pilot Non-Flying (PNF)	1
Air Traffic Control (ATC) / Ground Services	8

Compounded exchanges occur when a system entity provides multiple items of information within the same verbal turn. This is thought to lead to longer verbal exchanges. In the sources analysed, we observed that PF and PNF engaged in the least amount of compounded exchanges (11.1%), as compared to ATC and ground services (88.9%), during problem-solving exchanges.

Effectively compounded exchanges can minimise the cost of VHF-occupancy. However, ineffectively compounded information could lead the receiving party to initiate a turn-repair by requesting for the information to be repeated.

F. *Overlap and Problem Initiator*

TABLE IX. OVERLAP AND PROBLEM INITIATOR

Party Initiating an Exchange	Sum
Pilot Flying (PF)	2
Pilot Non-Flying (PNF)	3
Air Traffic Control (ATC) / Ground Services	11

Overlapping exchanges occur when a verbal turn is taken before the previous one is finished. In the sources analysed, turns were recorded mainly at a ‘second’ resolution such that overlap could only be inferred when they occurred within a second. However, some instances of human conversation can be less than a second such that two turns are taken at the same recorded time, but are actually sequential. We have taken this limitation into consideration and observed correlations with the entity initiating a problem-solving turn and the number of overlaps. PF and PNF have less overlapping turns (31.25%) than ATC and ground services (68.75%). This is thought to occur mainly because ATC requests are initiated, regardless of the ongoing conversation among the crew, due to the absence of perceptual cues between air and ground.

VII. CONCLUSION

This study showed a number of interactions among human and environmental factors on approach and in hazardous situations. We conclude that a number of those relationships are worth being investigated as potential, causally related factors. The uncertainty displayed verbally within the cockpit varies greatly (5.46%-32.09%) and correlates with a similar variation of cues indicating an uncertain event – however, all those situations are known to have ended in fatal accidents. The relative low frequency of ATC/Ground initiated problem-solving exchanges (7%) as compared to crews (93%) needs clarification since our correlation favours cockpit-occurring conversations. Crews were also seen to initiate 80.6% of problem-solving exchanges based on direct environmental cues

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while ATC/Ground initiated 19.4% based only on indirect cues. Finally, ATC/Ground initiated exchanges correlated with 68.8% of overlapping exchanges and 88.9% of compounded verbal exchange.

Finally, the limitations of this study are seen to arise mainly from two factors: the availability of original CVR data and the cockpit-centred perspective of verbal exchanges between air and ground teams. A further study of collaborative practices centred at approach centres and analysing controller problem-solving during uncertain situations is currently under way.

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