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Aviation Safety: An Initial Exploration of the Feasibility of Using Language Engineering Technologies for Reducing Pilot-Air Traffic Control Miscommunications

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ABSTRACT

This paper describes some initial investigations into the possibilities of using state-of-the-art language engineering technologies to minimise miscommunications between pilots and air traffic controllers. Despite considerable efforts to remedy this situation by providing solutions that focus almost exclusively on new proposals for making air traffic control (ATC) messages clearer and easier to understand and on better ATC communication training strategies, communication problems persist. In order to demonstrate this, we provide two examples from an aircraft accident and incident report respectively, both of which were identified as featuring communication problems between pilots and ATC. Results describe the types of miscommunication in their situational and operational contexts. It is then argued that employing automatic speech recognition (ASR) and machine translation (MT) techniques would have the potential to reduce these communication problems and hence might have contributed to preventing the accident and the incident from happening. This paper presents a snapshot of our initial work as well as thoughts on its future development, including a description of how an ASR-MT communication system might be designed and implemented into the flight deck and ATC workspaces respectively and how this system may impact on mental workload, situation awareness, and attention allocation.

Keywords: Attention Allocation, ATC Miscommunications, ATC Phraseology, Automatic Speech Recognition, Machine Translation, Mental Workload, Situation Awareness, Terminology

INTRODUCTION

Like the general topic of communication, ATC communications is a complex phenomenon involving a number of different aspects, such as those shown below. Research into the area of ATC communications tends to focus either on individual aspects or combinations of these.

- linguistic aspects (e.g. Cushing, 1994; Barshi, 1997; IATA, 2011)
- cognitive aspects (e.g. Reason, 2008)

- psychological aspects (Mosier, Rettenmaier, McDearmid, Wilson, Mak, Raj and Orasanu, 2013)
- communicative aspects (e.g. Linde, Goguen and Devenish, 1986)
- technical aspects (e.g. Cushing, 1994; O'Neil, 1999)
- human factors aspects (e.g. Hawkins, 2010)
- combinations of aspects (e.g. linguistic/cognitive; see Barshi and Farris, 2013)

The main means of ATC communications is using voice communications via very high frequency (VHF) and high frequency (HF) radio and also occasionally via satellite. To this end, specific phraseologies and terminologies have been created with a view to facilitating clear, unambiguous, concise, and efficient communications between pilots and air traffic controllers. The notion of ATC phraseology/terminology can be described as a restricted sublanguage with reduced vocabulary, clearly assigned terms, simplified syntax, and altered pronunciation. This controlled language aims at avoiding miscommunication by eliminating specific everyday linguistic devices, such as those listed below.

- Homophones[1], e.g. *to* vs. *two*
- Homographs[2], e.g. *close* (which can mean *near* or *shut*, and so on)
- Homonyms[3], e.g. *go ahead* (meaning *to urge speaking* or *to move forward*)
- Synonyms, e.g. *runway holding point* and *runway holding position*

The International Civil Aviation Organization (ICAO) has developed and published the ICAO ATC phraseology standard (ICAO, 2007), which is the international standard that should be adopted world-wide. However, IATA, the International Air Transport Association, has recently highlighted that unambiguous radio communications between pilots and ATC are routinely impeded as both groups often depart from this standard (IATA, 2011: 7-8), e.g. by using non-standard phrases such as *ready for take-off* instead of the ICAO phrase *ready for departure*. They also observe that the quality of English being spoken by both groups is characterised by more or less pronounced dialects and accents and that local languages are used frequently by pilots and air traffic controllers, although ATC communication regulations clearly stipulate that radio communications should be carried out in English at all times.

Numerous studies have attempted to improve communications between pilots and air traffic controllers, leading to a number of vital recommendations for improving ATC communications. Suggestions have, for instance, been made regarding ATC message lengths, message complexity and phraseology wordings (e.g. Barshi, 1997; Barshi and Farris, 2013). A large number of studies have put forward new methods and tools for improved training to help reduce errors in ATC communications (Cushing, 1994; Elliot, 1997; Robertson, 1997; Alderson, 2008, 2009, 2011; Farris, Trofimovich, Segalowitz and Gatbonton, 2008). Other studies have focused on the actual method of how to get ATC messages across to pilots and air traffic controllers. Text messaging, for instance, as an additional means to voice communications has been examined in studies on data link communications between pilots and ATC (e.g. Schneider, Healy, Barshi and Kole, 2011). ATC messages can be sent as text and shown as text on displays in the flight deck and on screens in the air traffic controllers' workspace. However, data link communications is a limited service as it is used only for en route navigation. In other words, it tends to be used during low workload phases of flight, typically in the cruising phase. It should be noted that pilots consider data link messaging as time-consuming and cumbersome to use (RB[4], personal communication, 27 August 2013). Barshi and Farris share this view saying that data link messages have a clear disadvantage over voice communications, especially when pilots are multitasking as they argue that pilots find it faster to speak on the radio than having to read text (2013: 189).

In contrast to the above studies, research into more comprehensive solutions that have the potential to overcome most of the issues involved in ATC communications are rare. An exception is Cushing who – in addition to suggesting more extensive training in ATC communications – has proposed a potential short-term solution in the form of using an error-resistant visual interface (1994: 98-110) and a long-term solution focusing on an intelligent voice interface (1994: 91-97). However, he has not completed these systems (cf. Barshi and Farris, 2013: 22).

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1 Words which are pronounced the same but are different in meaning (Crystal, 1992).
2 Words that have the same spelling but are different in meaning (Crystal, 1992).
3 Words with the same form but different in meaning (Crystal, 1992).
4 Capt. R. Bajaj, Training Captain B747-400, British Airways.

ATC MISCOMMUNICATIONS

While there have been many recommendations for making ATC communications less prone to error, it is nevertheless clear that there are still far too many barriers to safe communications between pilots and air traffic controllers – a situation which has obvious consequences for aviation safety. The difficulty lies not only in the large number of communication problems but also in the types of problem that can occur during ATC communications. In general, the issues of miscommunication can be categorised into five major groups[5]:

(a) The use of local languages during ATC communications
(b) The variations in English pronunciation by native and non-native speakers
(c) The variations in speech prosody, i.e. tempo, rhythm, pitch and loudness, by native and non-native speakers
(d) The use of non-standard phraseology
(e) A lack of global standardisation and harmonisation of ATC phraseology, resulting in several standards being in use, including

- the ICAO international phraseology standard;
- the CAA phraseology standard in the UK, which intentionally contains some non-standard phraseology (Skybrary, 2013);
- the standards by several other European countries, which have also adopted some non-standard phrases (Skybrary, 2013);
- the FAA phraseology standard in the US, which also employs non-standard phraseology;

While there are numerous publications on the communication problems arising from the use of non-standard ATC phraseology and terminology, it is rarely discussed that there are differing ATC phraseology and terminology standards in existence. An exception is the recent report from IATA which notes that there are critical differences (2011: 54) between, for instance, the North American ATC phraseology standard and the ICAO ATC phraseology standard. Some examples of such discrepancies are shown in Table 1 below.

Table 1: Examples of differences in ATC phrases and terms between ICAO, CAA and FAA

ICAO	**Civil Aviation Authority – CAA, UK** Adheres largely to ICAO standard	**Federal Aviation Authority – FAA, US**	**Definition of Concept**
vacate	vacate	exit	moving away from something
PAN PAN PAN	PAN PAN PAN	minimum fuel advisory	signalling emergency due to, for example, low fuel state
ramp	apron	apron runway tarmac	paved parking area excluding ramp and taxiway
line up and wait	line up and wait	taxi into position and hold	clear to line up on the departure runway but not cleared to take off
descend now	descend now	descend	ambiguity between descending now or later
taxi to holding position	taxi to holding position	taxi into position and hold	taxi to, and hold at, at a point clear of the runway

[5] There is another type of problem that can be experienced during ATC communications which, however, is not listed above as it does not seem to be mentioned in the relevant literature, yet is often experienced by pilots (RB, personal communication, 21 June 2013). This type of problem tends to occur in situations in which language beyond standard ATC phraseology has to be used. For example, when pilots who are English native speakers try to communicate with air traffic controllers whose first language is not English in a manner that is more appropriate for communicating with other English native speakers (e.g. by using idiomatic expressions, complex words, long sentences, and so on) breakdowns in communication often ensue. In such situations pilots who are English native speakers should instead use more easily understandable language, such as clear, simple and unambiguous English. This problem ties in with an observation made in the area of automatic speech recognition, which performs less well in situations when humans talk to humans whereas it performs much better when humans talk to computers since in such cases humans tend to speak more slowly, simply and clearly (Jurafsky and Martin, 2009). This type of communication issue could therefore be improved by specific training in the use of Aviation English which makes native speakers aware of the fact that they have to adjust their language when speaking to non-native speakers.

A typical example of a discrepancy in phraseology between the North American ATC phraseology standard and the ICAO ATC phraseology standard would be the situation of a civilian aircraft being in danger of running out of fuel during the landing approach.

- The ICAO phraseology taught to UK pilots stipulates that the pilot responsible for ATC communication has to declare an alert using the expression *PAN PAN PAN* followed by the mention of the call sign together with the nature of the emergency, e.g. low fuel state, to ATC ground control.
- In contrast, in US airspace pilots have to use the term *minimum fuel advisory* followed by the pilot's statement as to the number of minutes of fuel remaining.

As has been seen, the ICAO phraseology standard is the standard which ought to be used globally. However, to varying degrees, several countries have adopted their own phraseology standards (ICAO, 2007: iii) and these seem to have arisen from the fact that although ICAO emphasises that their standard ought to be adopted by all the stakeholders, they do in fact not have any powers to make it a prescribed standard and adoption of it is left to the countries participating in civil aviation. The reasons as to why individual countries are unwilling to adopt the ICAO standard may be due to cultural and political reasons. There may be a national reluctance in adopting a standard that is 'imposed' on them by an international organisation. In this context, the recent phraseology study by IATA highlights the 'hope' that their study "will provide momentum towards a greater harmonization of communications" (IATA, 2011: 54). However, it may be argued that the harmonisation of ATC phraseology and terminology is not something that should be left at the discretion of airlines and national aviation regulators but it is something that should be viewed as indispensable for improving aviation safety.

ATC communications is a highly safety-critical area in which the use of local languages as well as the use of non-standard ATC phrases and terms have already led to several fatal aircraft accidents (e.g. Avianca crash at New York in 1990; accident of the KLM and PanAm aircraft in Tenerife 1977), and hence it seems paradoxical that not only local languages are spoken during ATC communications, but also that pilots and air traffic control do not always adhere to standard phraseology and terminology and that differing ATC phraseology and terminology standards should exist in the first place. Variations in pronouncing English and speech idiosyncrasies are also a significant impediment to effective communications as even among English native speakers' variations in English pronunciation and idiosyncrasies, such as speaking fast, are known to cause problems. While the latter problem can be improved upon to a large degree by speech training, the problems of using local languages and non-standard phraseology are more difficult to solve.

Pilots, in particular, get very confused when they are, for instance, on the approach to a foreign airport and they can hear ATC speaking to another aircraft on the same flight path in a local language. Those pilots who are unable to speak the local language will not know what that particular aircraft is doing in terms of altitude, speed, heading, and so on (AB[6], RB, personal communication, 22 July 2013). The non-adherence to standard phraseology by pilots and ATC is seen as equally as dangerous as this can and has often led to confusion and fatal accidents, for instance, when it comes to line-up and take-off clearances (e.g. accident of the KLM and PanAm aircraft in Tenerife 1977). In the case of the existence of several phraseology standards, it is a well-known psychological phenomenon that when facing situations in which human beings have to perform under stress (e.g. emergencies) they may revert back to 'old behaviour' (cf. Reason, 1988; Bourne and Yaroush, 2003; Covelli, Rolland, Proctor, Kincaid and Hancock, 2010), i.e. to what they know best or have learnt first. This can even be the case in spite of regular emergency training. Hence, a pilot flying for a non-US airline may, as has been the case in the Avianca crash in 1990, use the wrong phrase in an emergency situation in US airspace when facing an extreme emergency situation.

Since voice communications are beset with many problems and the data link communication service has not been able to improve ATC communications significantly, it is vital that pilots and air traffic controllers be given an additional communication method which has the potential of dealing with and reducing all of the above-mentioned communication issues. The solution that is proposed in this research is to create a communication system based on the latest language engineering technologies. In particular, it is planned to use automatic speech recognition (ASR) and machine translation (MT) technology.

[6] Capt. A. Bridger, Chief Pilot Boeing Fleet, British Airways.

THE POTENTIAL USE OF LANGUAGE ENGINEERING TECHNOLOGIES FOR REDUCING ATC MISCOMMUNICATIONS

Automatic Speech Recognition

The goal of automatic speech recognition (ASR) is to transfer speech to text. Spoken words are converted into written words by decomposing a word into smaller units of speech (Jurafsky and Martin, 2009: 249). The smaller units of speech then form the basis for speech recognition algorithms which change a sequence of acoustic waves into a sequence of written text. The problem of speech being automatically recognised irrespective of any surrounding conditions is still difficult, but lately progress has been made for ASR to work feasibly in some areas (Jurafsky and Martin, 2009: 319), e.g. human-computer interaction, where speech is seen as a more suitable input method for certain tasks than, for example, typing, and the domain of telephony (2009: 319), where users can, for instance, book flights, tickets, make appointments, and so on. Other areas of automatic speech recognition that are important for this research are dictation, by means of which users can have their dictated speech transcribed into written text, and real-time subtitling using respeaking technology. Of particular relevance here is also the use of ASR systems in military aircraft, e.g. direct voice input by pilots in the Eurofighter Typhoon (2014); pilot-aircraft F-35 speech system (Schutte, 2007), and the training of air traffic controllers using automatic speech recognition systems (Karlsson, 1990; Klie, 2010), the latter of which is currently used by, for example, the US FAA in their ATC simulators. Further examples of modern ASR usage are the areas of healthcare (e.g. for MS sufferers, quadriplegics), speech-enabled smartphones, and so on.

The ideal performance situation of an ASR system would be if the system recognised everything a speaker said without any time delay (real time factor, RTF) and with a 0% word error rate (WER) irrespective of vocabulary size, prosody, accents, dialects and channel/noise issues. In reality, however, the existence of bottleneck areas (vocabulary size, noise, speech characteristics) of ASR systems means that the performance levels in terms of accuracy and speed will be affected negatively, but it is nevertheless possible to raise them by applying certain constraints. For instance, such constraints would include smaller vocabulary sizes, reduced noise, the use of high-quality channels, and training the systems on individual speakers. In contrast to older systems, modern ASR systems are trainable (Jurafsky and Martin, 2009: 207) as their technology is based on statistical models. If such a system is trained on a particular speaker, it then becomes possible to increase the size of the vocabulary. As ATC phraseology is a sublanguage with already reduced vocabulary and with altered pronunciation, the performance levels of ASR would be expected to be much higher than with general language.

Machine Translation

Machine translation (MT) performs translation from one language to another by computer without human intervention, except for the stages before and after the translation process where human assistance may be necessary (Forcada, 2010). According to the European Association for Machine Translation (EAMT), "today a number of systems are available which produce output which, if not perfect, is of sufficient quality to be useful in a number of specific domains" (2013:1). Nowadays there is also increasing demand for integrating MT technology with other language engineering technologies, for instance, with speech input/output systems – an integration of technologies which we would also like to achieve in order to remedy the continuing ATC communication issues.

The state-of-the art technology used in MT systems is hybrid, which brings together rule-based as well as statistical and example-based methods. One of the most well-known machine translation engines is Systran, which is a hybrid engine which combines a rule-based approach to machine translation (RBMT) with a statistical approach to machine translation (SMT). Systran is of particular interest here as its hybrid methods are well suited for dealing with spoken languages, as would be the case in ATC communications. The RBMT part of Systran's hybrid approach enables high-performance consistency and predictability of translations as well as high adherence to terminology and phraseology – which would be a salient requirement for ATC communications. The main advantage of this combined approach is that within a particular domain, e.g. ATC communications, the quality of translations is improved substantially.

Like ASR systems, the performance of MT systems depends on many problems inherent in language and speech, such as different grammatical structures, and on the linguistic devices used, including homonymy, polysemy[7] and synonymy. MT performance increases the more a domain is delimited as high-quality results have, for example,

[7] Words with the same spelling and pronunciation which have different but related meanings.

been achieved in the domain of meteorology (Gotti, Langlais and Lapalme, 2013), which is characterised by weather reports in standardised form, reduced and disambiguated terminology, controlled language (e.g. limited use of syntax), and repetitive information (cf. Jurafsky and Martin, 2009: 898). ATC communications constitute a similarly restricted language and delimited domain.

The Proposed ASR-MT Communication System

Key findings in the areas of ASR and MT make it clear that both ASR and MT systems tend to produce results of varying levels as their performance depends on how well problems such as dialects, accents, prosody, channel, background noise, vocabulary size, domain delimitation, grammar differences, and linguistic devices are dealt with. Consequently, the task of creating an ASR-MT communication system will not be an easy one. However, as we have seen, both technologies perform considerably better when dealing with standardised and restricted sublanguages, to which ATC phraseology belongs. We hope that the proposed ASR-MT system will be able to reduce the aforementioned ATC communication problems in the following ways:

- Addressing Problem (a)
  Whenever local languages are used by pilots and air traffic controllers it is planned that the system will enable textual translations into English in real-time. The translations should be displayed on suitable screens in the flight deck and in the air traffic control work environment.

- Addressing Problems (b) and (c)
  State-of-the-art ASR systems are trainable on the speech idiosyncrasies of individual speakers and are hence more able to deal with variations in pronouncing English and with speech prosody than older ASR systems.

- Addressing Problems (d) and (e)
  It is planned that the system will convert spoken English ATC messages into text in real-time in order to enable pilots and ATC to spot non-standard phrases. Like the translations for messages in local languages, these textual ATC messages should also be displayed on suitable screens in the flight deck and in the ATC workspace.

When designing the suggested ASR-MT communication system, it ought to be borne in mind that the system needs to be interfaced with the radio communications system. The new system should provide pilots and air traffic controllers with textual versions of transmitted voice messages. For example, for every voice ATC message to a specific aircraft a transcribed text version would be displayed in real-time on a screen on the flight deck of that aircraft. At the same time, any other aircraft which is in the same airspace on the same radio frequency (or happens to be on the ground at the same airport) and which has the ASR-MT communication system installed would also receive the text version of that particular ATC message on their displays, just like they can hear and listen to ATC messages intended for other aircraft. If, for instance, a local language is used during ATC communications, the MT system would get activated in addition to the ASR system and the pilots and air traffic controllers would receive the English translations of what has been transmitted in that local language on their respective displays in real-time. In this way, pilots from other aircraft would always be able to understand ATC transmissions in a local language between, for example, a neighbouring aircraft and air traffic control and be in the picture about what that specific aircraft is doing or not doing. In other words, pilots and air traffic controllers would benefit from improved situational awareness.

The ASR-MT Communication System on the Flight Deck

Depending on the individual phases of flight (e.g. pre-flight, take-off, cruise, and so on), it will be up to the pilots to decide whether they wish to look at the text displayed on the screens. For instance, as long as a pilot dealing with ATC communications (pilot not flying) hears ATC phraseology in English as well as in standardised form, s/he will likely not need to look at the text display. However, if local languages are used on the radio, the pilot not flying will probably want to read the ATC instructions in English on the display in order to find out what is going on in the airspace around him/her or on the ground when taxying and especially any time near the runways. Similarly, even if ATC communications are conducted in English it may be that the pilot not flying detects some non-standard phrases transmitted by ATC or other aircraft on the radio. The pilot can then double-check this on the text display and, if necessary, decide to ask air traffic control for clarification.

In a multi-tasking work environment where pilots handle several tasks at the same time using their hands, eyes, speech, and other senses, giving them the option of reading or ignoring the textual displays means that during times of high workload (e.g. take off, approach) a pilot not flying would only have to read the textual displays if absolutely necessary. This would be particularly important during safety-critical situations where it is salient that ATC communications are accurate. The ASR-MT communication method therefore has the potential to reduce situations of high workload since pilots would have more time to 'aviate and navigate'[8]. When workload increases, communication tends to disintegrate (cf. Billings and Cheaney, 1981; Barshi and Farris, 2013). For example, it has been reported that pilot-to-controller communications decrease in length under high workload (Raby and Wickens, 1994). To put it generally, the pilots' sense of hearing is the first one to become negatively affected (cf. limited-channel-capacity model, Jennings and Chiles, 1977; Wickens, Vidulich and Sandry-Garza, 1984) before the other sense organs, such as the eyes – this would make reading a preferred option over listening. With the help of the proposed ASR-MT solution, communication would be aided by text displays which enable pilots to save valuable time since being able to read textually displayed ATC messages on the navigation screens as and when necessary for safety reasons is a task that is perceived by pilots as much faster than physically having to ask the controller for a read back (RB, personal communication, 21 June 2013; for an opposite view cf. Barshi and Farris 2013: 189). Hence, it seems more suitable to give pilots under heavy workload the option to read text only if required and allow them to focus on 'aviating and navigating'.

It should be noted that even though error rates in the ASR-MT system may turn out to be not as low as desired and translation speeds may at times not be as fast as required, it is nevertheless argued that such results can be of use to pilots and air traffic controllers, in particular in safety-critical situations. For instance, even if a translation of a foreign-language ATC message may be stilted or slightly confusing, or even if a non-standard ATC message results in a rough or incomplete transcript, such results can nevertheless be seen as an improved communication situation. Pilots could get at least an idea as to what was said by looking at the textual displays. If they can detect any safety-critical terms, e.g. *runway*, *holding position*, *take-off*, *landing clearance*, and so on, they argue that they would nevertheless have better situational awareness because of this (RB, personal communication, 01 June 2013).

The ASR-MT Communication System in the Air Traffic Controllers' Workspace

Various studies have noted that in ATC, communication errors between controller and pilots can cause numerous safety occurrences. The types of errors most prevalent in ATC are:

1. Readback/Hearback errors Type I – The pilot reads back the clearance incorrectly and the controller fails to correct the error.
2. No pilot readback.
3. Hearback errors Type II – The controller fails to notice his/her own error in the pilot's correct readback or fails to correct critical erroneous information in a pilot's statement of intent.

The role of ASR-MT communication systems in avoiding such occurrences becomes evident. There should be no ambiguity of the critical information regarding a clearance with the technology and the pilot and the controller will not mishear any callsign, altitude or speed, irrespective of dialects, and so on. This in turn will improve the situation awareness of air traffic controllers as well as enable the workload to be managed appropriately.

Examples of Miscommunications

In what follows, real-life examples of ATC miscommunications are presented and discussed with a view to seeing whether they could have been prevented by the use of an ASR-MT communication system on the flight deck and in the air traffic controllers' workspace. The data on ATC miscommunications were obtained from two different reports – one reporting on a fatal accident and the other on an incident.

(1) Flying Tiger Line, FT66, Singapore – Kuala Lumpur, 19 February 1989, accident with fatalities (Aviation Safety Network, 1989).

During the descent to Kuala Lumpur, the crew was cleared by ATC to route directly to the Kayell (KL) beacon. Malaysian ATC transmitted to the crew, "Tiger 66, descend two four zero zero", meaning that the pilot should descend to an altitude of 2400 feet amsl (above mean sea level). The captain, who had understood "descend to four zero zero", read back "Okay, four zero zero". This meant that he was planning to descend to 400 feet amsl – 2000 feet too low. The air traffic controller did not pick up on the wrong altitude in the captain's read back.

The air traffic controller did not use standard ATC phraseology. Instead of transmitting "descend two four zero

[8] Pilot training teaches the priority order "aviate-navigate-communicate" (Owens, 2013; Barshi and Farris, 2013).

zero", he should have said "descend and maintain two thousand four hundred feet". In addition, the captain also used non-standard ATC phraseology when replying "okay, four zero zero" whereas the correct standard phrase should have been "Roger, descend and maintain four-hundred feet", which should have allowed the air traffic controller to notice the incorrectly read back altitude. The Boeing 747-249F eventually descended below minimum altitude and crashed into a hillside at ca. 600 feet amsl just before reaching the Kayell beacon, where minimum descent height has to be 2400 feet. There were no survivors.

The cockpit voice recorder that was retrieved also revealed several other communication errors made by the flight crew before the miscommunication about the descent altitude took place as well as confusion with regard to the acronym 'KL' used to refer to the Kayell beacon. This code was also employed by local air traffic control to refer to Kuala Lumpur instead of using the full expression 'Kuala Lumpur'. There were also other errors committed by the flight crew, such as completely ignoring the continuous warnings of the on-board Ground Proximity Warning System. The accident investigators concluded that this fatal accident was mainly caused by the crew's lack of abiding by the correct instrument approach procedure, by the captain's inadequate crew resource management and the flight crew's diminished situation awareness. However, the fact that non-standard, i.e. incorrect ATC phraseology by both the pilots and local air traffic control was used was also seen as a major contributing factor to this accident.

(2) Runway incursion during take-off at Paris-CDG, 10 January 2010, incident (BEA, 2007).

This incident occurred between a British-registered airliner (Airbus A321) and a French-registed airliner (Airbus A340). The scenario was that a third Airbus A320 had made an emergency landing on runway 27L at Paris-CDG. It had exited the runway via a taxiway and was being inspected by emergency vehicles. Meanwhile, the British-registered A321 had landed on the parallel runway 27R and was given instructions to vacate this runway via a taxiway. Simultaneously, the French-registered A340 was at the threshold of runway 27L awaiting take-off clearance. The air traffic controller then gave take-off clearance to the A340, which was issued in French. At the same time the British A321 was given clearance to cross runway 27L – the same runway on which the French A340 was in the process of taking off. Since the take-off clearance was given in French, the British A321 crew were unaware that they had now been put into a runway incursion situation. The automated airport collision alarm sounded and the French air traffic controller realised his mistake and ordered the French A340 to abandon its take off immediately. The French A340 was able to stop in time to avoid a collision.

Apart from various other factors that contributed to this incident, such as that the air traffic controller was distracted by the emergency landing of the A320, the way strips boards were managed by ATC, how resources were managed in the ATC team, and so on, it was noted that the use of both English and French during ATC communications between flight crews and ATC does not allow crews who are not able to understand and speak French to have adequate situational awareness of the traffic situation close to and or on the runway or allow them to able to spot any ATC errors. It was also mentioned in the accident report by the French air accident investigation bureau that "the French-speaking crews were less attentive to messages given in English, because they were not addressed to them" (BEA, 2007: 4). Figure 1 below illustrates the positions of the three aircraft relative to each other when the incursion occurred.

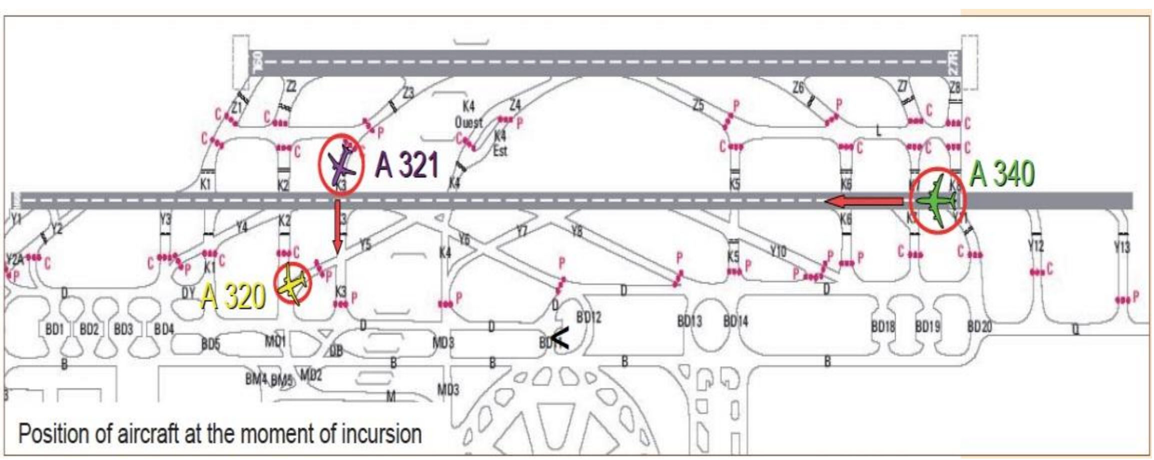

Figure 1. Paris-CDG runway chart (taken from BEA, 2007)

Would the Proposed ASR-MT Communication System have made a Difference?

Had the ASR-MT system been implemented in an appropriate screen on the flight deck of the Flying Tiger aircraft as well as on suitable screens in ATC, it might have been possible for both the crew and the air traffic controller to notice that non-standard phraseology was used.

The first phrase used by the air traffic controller "Tiger 66, descend two four zero zero" would have in all likelihood been rendered correctly by a trained ASR system. The system would have displayed this message via respeaking technology on an appropriate screen in the flight deck, which would have given the crew an opportunity to spot the fact that the intended descent altitude would have been 2400 feet, and not 400 feet, as the captain had understood. The discrepancy between what the captain had heard and what he would have seen on the screen might have shifted the attention of the crew and given them the chance to double-check the altitude with ATC. In case the crew had chosen to ignore this message on the screen there would have been a second chance to pick up on the altitude error during the second transmission when the captain read back "Okay, four zero zero" since this message would have been displayed on the appropriate ATC screens and the air traffic controller might have picked up on the wrong altitude when looking at the display.

There is obviously no guarantee that the Flying Tiger pilots would have looked at the text displays as they were likely overloaded with the situation in the flight deck, which is indicated by the fact that the continuous alarms from the Ground Proximity Warning System were completely ignored. However, it is argued that the availability of textual displays of ATC messages would have at least provided the pilots with additional opportunities to regain their situational awareness. The fact that the system is meant to work simultaneously in two workspaces, i.e. both the pilots and the air traffic controllers have textual displays at their disposal, might mean that this type of communication system has the potential to break the chain of causative events in the case of miscommunications.

In the case of the Paris-CDG runway incursion, the MT engine would have been activated in addition to the ASR system and would have supplied the pilots of the British A321 aircraft with English translations of the French ATC messages on a screen in the flight deck. This would have instantly increased the British pilots' situational awareness around runway 27L and allowed them to question ATC with regard to the appropriateness of their runway crossing clearance. Even if the translated ATC message had not been grammatically and semantically perfect, it is likely that the key terms contained in the ATC message would have been translated correctly. In this example, this would have been safety-critical terms such as *take off*, *runway 27L*, which would have alerted both pilots in the British A321 of a potential conflict and would have made them question ATC. Hence, even the display of an ungrammatical or semantically slightly incorrect translation can save an airliner from an accident or incident.

HUMAN FACTORS CONSIDERATIONS

Flight decks and air traffic controllers' workspaces are environments in which very high workloads can be experienced at times during particular phases of flight (e.g. take off, landing), certain times of day, and emergency situations. It is therefore vital that the proposed ASR-MT communication system is integrated in both work environments in such a way that it will not negatively impact on the mental workload, attention allocation, and situation awareness of both groups of professionals. For example, today's highly automated cockpits are designed to reduce workload but the pilots are still fully responsible for the automated tasks, procedures and processes (Wickens and McCarley, 2008:4). As a result of this automation, pilots may not allocate much attention to the automated tasks and procedures with the effect that this may result in reduced situational awareness. As Wickens and McCarley point out such a situation could have disastrous consequences when the automated processes stop working.

At this stage of the research we can only speculate on how the proposed textual communication system will impact on the pilot's highly automated workplace and the air traffic controllers work environment in terms of mental workload, situation awareness and attention allocation.

In the case of pilots, it is not uncommon for them to be uncertain about the content of ATC communications and quite a considerable amount of time is spent discussing with each other the meaning of ATC messages which invariably requires querying ATC to make sure the pilots have not misunderstood. In these cases, the implementation of the textual communications system would seem to suggest that workload could be reduced and would resolve any uncertainty about ATC messages among the pilots much faster (RB, personal communication, 21 June 2013). Pilots would have more time to 'aviate and navigate'. As a direct result of having ATC messages at their disposal at all times, the pilots' situation awareness would be increased throughout, in particular in situations where ATC or pilots from other airlines use local languages. Even a less well translated message would help if a local language is used on the radio as pilots could at least get an idea about what was said by looking at the textual displays. If they can detect any safety-critical terms, e.g. *runway*, *holding position*, *take-off*, *landing clearance*, and so on, it is argued that pilots would nevertheless have better situational awareness because of this. In terms of attention allocation, it may be necessary for the pilots to be specifically alerted to the textual displays of incoming ATC messages if some of these contain safety-critical terminology such as *runway*, *take off*, *descent*, *climb*, *turn*, *heading*, and so on. In order to make sure that the usual order of attention scanning is interrupted so that the new and important information is processed instantly (cf. Wickens and McCarley, 2008) the use of a cue may have to be considered in order to direct the attention of the pilots to the respective screen in a manner that is as little disruptive as necessary. For instance, depending on what works best in a busy and noisy cockpit environment either a visual or audible cue needs to be taken into account when designing the ASR-MT communication system (cf. Wickens and McCarley, 2008).

In the air traffic controller's workspace, considerations of workload, situation awareness, and attention allocation are equally as important. The use of the ASR-MT communication system will provide improved situation awareness for controllers as the lack of ambiguity in communications will greatly enhance the accuracy of the information provided to controllers. This being the case, then the certainty of information will in addition enable controllers to manage their workload in a fashion considerably more enhanced than at present. The potential of the technology is to reduce, if not altogether remove, ATC communication errors.

CONCLUSIONS AND FUTURE DEVELOPMENT OF THE WORK

In this paper we presented a snapshot of our initial work as well as thoughts on its future development, including a description of how an ASR-MT communication system might be designed and implemented into the flight deck and ATC workspaces and how this system may impact on mental workload, situation awareness, and attention allocation of pilots and air traffic controllers respectively. This research idea is in its development stages. At present, partners to the research are being established and a submission for funding is being prepared. Next steps include the setting up of a pilot study to examine the ATC communication problems in depth, to establish what solutions pilots and air traffic controllers ideally would like to see implemented, to gauge their reactions and thoughts on the proposed communication system, and to survey the existing technologies for ASR and MT.

The recently conducted Pilot and Air Traffic Controllers' Phraseology Study by IATA has highlighted that some language-based problems in ATC communications, such as idiosyncratic speech and the use of local languages, cannot be resolved easily or at all through further training. However, no solutions are offered as to how such language-based problems could be minimised. In fact, IATA emphasise that their study is only a starting point for highlighting the continual presence of ATC miscommunications as well as the necessity for further research in this area. It is hoped that through the present research it will be possible to make a contribution to decreasing ATC miscommunications.

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