

FACTORS AFFECTING COMMUNICATION IN AVIATION

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Abstract

This paper draws together the results from several studies investigating factors which affect communication in aviation: native language, speech rate, information density, and workload. The data for these studies include recordings of pilots in flight simulator experiments as well as recordings of pilot-ATC radio communications in both domestic and international operations. The results show complex interactions between the variables analyzed, with native language playing a smaller role than often assumed.

Keywords: communication, native language, speech rate, workload, duty time

1. Introduction

The main goal of the research program presented in this paper has been to investigate how factors which are known to affect communication contribute to incidents of miscommunication with potentially disastrous consequences in aviation. This research has been conducted over several years at the University of New South Wales (UNSW) and has involved a number of students and colleagues, who all contributed to the studies reported in this paper.

1.1. Communication and aviation safety

Communication is one of the human factors which is crucial for aviation safety. Serious breakdowns in communication or even simple misunderstandings have long been recognized as contributing to many aviation accidents and incidents [1, 2]. Put simply, the fundamental issue is that communication over the radio between pilots and Air Traffic Controller Officers (ATCO) is difficult because there is a large amount of precise information to be transmitted at a very fast pace in conditions of high workload in a noisy environment.

1.2. Standard Phraseology

In addition to noise, the physical limitations of the radio medium itself (i.e., multiple speakers on a single channel and limited bandwidth), require that aviation communication conducted over the radio be highly constrained and codified. This led to the development of an 'aviation language' which differs from ordinary conversational language at four levels.

Pragmatic level: The dialogue structure is explicitly marked, with a strict turn-taking protocol. Speaker identification is expressed with call signs at the beginning and/or end of transmissions, as in example (1).[1]

[1] All the examples in this paper are drawn from the data collected and analyzed for the research reported here.

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ATC: *(aircraft call sign) airborne contact approach runway 29 cleared for take-off* (1)
Pilot: *Runway 29 cleared for take-off (aircraft call sign)*

(Chow et al. in prep.)

Grammatical level: There are few pronouns, only simple questions, and negation should be expressed as shown in (2).

ATC: *National Cargo 891, confirm, do you need any fuel dumping?* (2)
Pilot: *NCR-2, Negative, National Cargo 891.*

(Estival et al. 2023)

Lexical level: The vocabulary is restricted, with prescribed phraseology to replace some common words, as shown in (3).

track (not *direction*); *climb* (not *go up*) (3)

Phonological level: To avoid possible confusions, specific pronunciation for numbers is recommended, as in (4).

/tri:/ (*tree*, not *three*); /faɪf/ (*fife*, not *five*) (4)
/naɪner/ (*niner*, not *nine*); /tauznd/ (*thousand*, not *thousand*)

Taken together, the restrictions and prescriptions at these four levels constitute 'Standard Phraseology', which must be adhered as much as possible in all aeronautical communications, as mandated by the International Civil Aviation Organization [3, 4]. In circumstances where no specified phraseology is available, the use of 'Plain English' is tolerated [5]. However, the language used must still always be concise, precise, and non-ambiguous; it must follow radiotelephony phraseology as closely as possible and should only be used when no phraseology is available.

Deviations from Standard Phraseology are well-documented causes of miscommunication in aviation [6]. Also known to affect communication are physical and environmental factors such as noise or poor radio quality, linguistic factors such as accent, speech rate and language proficiency, as well as cognitive factors such as excessive amount of information (more than four information items per transmission) and high workload [7].

1.3. Research background

The early stages of this research program were conducted via questionnaires distributed at flight training organisations in the Sydney Basin to establish the nature and prevalence of miscommunication in general aviation. The responses to the questionnaires showed that, contrary to expectations, pilots found that *Understanding other pilots* was more challenging than *Understanding Air Traffic Controller Officers* (ATCO), *Remembering what you have to say* or *Saying what you have to say*. Another unexpected result was the level of antagonism expressed by pilots identifying as native English speakers towards non-native English pilots [8, 9].

The results of a study of the improvement in communication from the use of noise-attenuation headphones with subjects from the same Sydney Basin population indicated that, when exposed to noise typical of that experienced in a GA cockpit, noise-attenuating headphones improved the subjects' ability to accurately identify and repeat words provided verbally. The benefits of the technology extended to non-native English speakers, but the relationship was slightly more complex,

as noise-attenuation headphones also improved the ability of speakers who were not familiar with the specific dialect of aviation English [10].

We then conducted a series of experiments in a flight simulator with pilots from the same area (Sydney Basin). For the analysis of the data from these experiments, communication errors were defined as either *omissions* or *mistakes* on *words* or *numbers* in pilot transmissions. The analysis of the flight simulator audio data established a methodology for comparing the pilot utterances that were recorded with the transmissions that would be expected in the particular context and situation (see example below) [11].

The research then progressed from the study of the audio data collected in the flight simulator experiments to the analysis of *LiveATC* recordings (https://www.liveatc.net/), using the same methodology [12, 13]. Following the detailed analysis of an incident at Narita in July 2021, the taxonomy of communication errors was extended to include *additional* (extraneous) words, including politeness markers [14, 15].

2. Effect of speech rate, information density and workload

The flight simulator experiments investigated the effect of ATC *speech rate*, *information density* in ATC transmissions and increased pilot *workload* on general aviation pilots. The recommendation from ICAO is that the speech rate in radio communication should not exceed 100 words per minute (WPM) [16], but pilots often complain about the fast speech rate of ATC instructions and previous research found that "fast speech rate from native English speakers tends to be problematic for non-native English speakers" [17]. While previous research also established that there should not be more than four information items in one transmission [7, 18], pilots still complain about overly complex instructions from ATC [6]. Workload of course has long been recognized as contributing to human errors [19, 20]. The stimuli for these experiments, which consisted in pre-recorded instructions from ATC for the different flight conditions, were designed and recorded by aviation professionals.

2.1 Dataset

Seventeen pilots completed the tasks, out of 18 recruited (one pilot elected to discontinue). The independent variables were language background (i.e., Native English Speakers (NES) vs. Non-native English speakers (NNES)); pilot qualification, i.e. Low (PPL or less) vs. High (CPL or higher); number of flight hours; and flight condition. There were four different flight scenarios, each with two varying conditions: ATC speech rate (normal vs. fast), information density (low vs high), pilot workload (low vs high), and frequency congestion (low vs. high),[2] giving a total of 2,142 transmission opportunities to the pilots.

The pilot transmissions were transcribed and compared with the expected transmissions in that context. For instance, in example (5) from the high workload condition, Pilot 10 made 3 errors: 2 mistakes (*Track 180* instead of *270*; *Altitude 4500* instead of *5500*) and one omission (*Transponder code 5033*).

ATC:	*ABC. Sydney Centre. You are identified at 4500 South-West of Wilton. Track 270 and climb to 5500. Squawk 5033 and contact Wilton 126.7.*	(5)
Expected:	*(Track) 270, (Climb to) 5500, (Squawk) 5033, (Contact) Wilton 126.7. ABC.*	
Actual (P10):	*4500 feet, 180 degrees, 126.7 at Wilton, we will be…tracking to Bathurst due to weather.*	

(Molesworth & Estival, 2015)

[2] No significant effect of *frequency congestion* was established for the data in this study.

2.2. Results

The analysis of the audio data confirmed the expectation that the *speech rate* and the *information density* in ATC instructions would affect the communication accuracy of NNES pilots to a greater extent than the communication accuracy of NES pilots. Indeed, overall, NES pilots committed fewer communication errors than NNES pilots. However, the NES/NNES distinction was confounded in the two conditions of higher *information density* and greater pilot *workload*. Both increased workload and high information density had a significant impact on all pilots' performance but showed no difference between NNES and NES [11, 21, 22].

The NES/NNES distinction was also confounded for *ATC speech rate* by pilot qualification. Fast ATC speech rate had a significant impact only on low qualified NNES pilots (PPL or less). Intriguingly, in the fast ATC speech condition, NNES with high qualifications performed better than NES with low qualifications (see Figure 1). These results led the research into a new direction: to investigate not only the impact of NNES learning English on aviation communication problems, but also the contribution of NES not using standard aviation language.

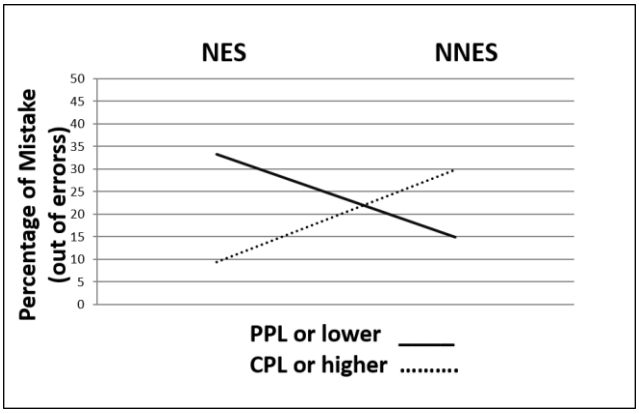


Figure 1. Mistakes in the fast speech rate flight, for pilot qualification and language background [11]

A further analysis aligned the flight simulator data with the audio data. It demonstrated that all pilots, regardless of their flying experience or language background, were able to follow ATC instructions even while they were committing communication errors, thereby validating the importance of stressing the old adage "*Aviate*, *Navigate*, *Communicate*" during flight training [23].

3. Effect of accent and language alignment in international communications

Following the flight simulator experiments, subsequent studies were specifically designed to examine the effect of the *accent* (whether native or non-native English sounding) of pilots and ATC on (mis)communications by commercial pilots [12, 13]. To this end, recordings obtained from *LiveATC* for international airports were transcribed and analyzed. To ensure comparison with the flight simulator study, the effects of the rate of speech in ATC transmissions and of the complexity of ATC transmissions (i.e., information density) were also examined.

In addition, given the results of [24], who found that language alignment between pilots and ATC in Bangkok (i.e., Thai pilots and Thai ATC) resulted in fewer communication errors than when language was not aligned, the studies also investigated whether accent alignment, where both interlocutors share the same language background, has any impact on miscommunication. Because information about the native language of speakers is not available in *LiveATC* data, pilots were classified as *accented* or *native English sounding* or accented rather than NES or NNES [12].[3]

[3] "Pilots were classified as 'native English sounding' if no foreign accent could be detected and if they were flying with an airline registered in a country where the official language is English (e.g., Australia, New Zealand,

Politeness markers, being additional words that could clutter transmissions, are not recommended in aviation communication but it has been suggested that inserting politeness markers in ATC-Pilot transmissions could have a positive effect because of perceived greater cooperativeness [25, 26], so the presence of politeness markers was also examined.

3.1 Datasets

The first *LiveATC* study looked at 18 hours of radio transmissions recorded at Sydney International Airport in 2016, yielding a total of 273 transmissions (132 *accented* and 141 *native English sounding*) [12]. The second *LiveATC* study analyzed approximately 1,000 ATC-Pilot transmissions recorded in October-November 2016. This second dataset comprises 250 transmissions at each of four international airports: Kingsford Smith, Sydney, Australia; Hong Kong International Airport; Los Angeles International Airport, USA; and Haneda, Tokyo, Japan [13].

3.2 Results

The results revealed complex interactions between the *alignment* (or congruence) of language background (i.e., same or different accent), and the factors of *information density* and *speech rate*. As expected, longer messages increased the number of communication errors and pilots committed fewer errors when the readback order was not scrambled. However, what was unexpected was that, in the second study involving four different international airports, native English-sounding (*NES*) pilots committed more errors than *accented* pilots. Even more unexpected was that the alignment of pilot and ATC language background only reduced communication errors when *NES* were not involved. That is, there were more errors when one speaker was a native English speaker.

In the first study (the smaller dataset from Sydney International Airport only) *accented* pilots made more errors in their transmissions than *NES* pilots, but they made different *types* (i.e., mistakes vs. omissions) of errors: *NES* did not make any mistakes, only omissions while *accented* pilots made some mistakes as well as omissions. The *category* (i.e., words vs numbers) of error is important because numbers are crucial elements of information for aviation (e.g., for altitude or heading, and errors on numbers can have disastrous consequences). *Accented* pilots made more errors with words than *NES* pilots, but both groups made similar numbers of errors with numbers (only omissions). In the second study (the larger dataset from four international airports), *accented* pilots committed fewer errors than *NES* pilots, but both groups made mistakes with both words and numbers.

Regarding the potential impact of *politeness markers,* the question was whether there would be more such 'relational expressions' in longer conversations, as these can indicate an operational issue or a misunderstanding, and in conversations which contain communication errors; both hypotheses were confirmed. On the other hand, the hypothesis that there might be more politeness markers when language backgrounds between pilots ad ATC are aligned was disconfirmed: there was no effect of language (accent) alignment on the presence of politeness markers [15].

In addition, although these additional relational expressions did not affect communication in this dataset, as there was no significant effect on communication errors, the study revealed that *NES* pilots and ATC used a wider variety of politeness markers with more idiomatic expressions than *accented* pilots or ATC. Given that ICAO (2010) recommends that native English speakers should 'refrain from the use of idioms, colloquialisms and other jargon', the study also proposed to reduce this variety by limiting relational expressions to four types: '*bye'*, '*good day'*, '*sorry'*, and '*thanks'* [15].

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the United Kingdom, or the United States of America). Pilots were classified as 'accented English' if a non-native English accent could be detected and if the aircraft was registered in a country where English is not one of the official languages (e.g., Japan, Korea, China, Chile). Pilots with an English sounding accent, but who were on an aircraft that was registered in a country where English is not the official language or is one of several official languages (e.g., Hong Kong, Singapore, Malaysia, Fiji) were excluded, as it was less certain whether their native language was English." (Wu et al 2019, p.3)

Finally, one important result from the *LiveATC* data analysis is the confirmation that the speech rate of both pilots and ATC largely exceeds the 100 WPM recommended by ICAO, as shown in Figure 2.

Location	Speaker	Mean
Sydney	Pilot	210.85
	ATC	202.48
Hong Kong	Pilot	246.39
	ATC	210.28
Los Angeles	Pilot	232.27
	ATC	233.62
Haneda	Pilot	228.46
	ATC	204.38

Figure 2. Speech rate (WPM) at four international airports [13]

4. Effect of fatigue from flight duty time and tempo of operations

A more recent study aimed to understand the fatiguing effect of flight duty time and tempo of operations on communication errors by analyzing data collected from commercial domestic flights in Australia between October 2023 and March 2024 [27].

The pace at which work is performed, otherwise known as work tempo, and the duration of time on task, referred to as duty time (or 'block time' in aviation), are known to exacerbate fatigue [28]. For work tempo, this is thought to result from cognitive load, defined as mental strain in task completion, while for duty time it is thought to result from wakefulness. Either have the potential to impair cognitive functions such as attention, memory and decision-making [29]. It has been shown that high workload levels dramatically increase the likelihood of communication errors among pilots and ATCOs, lowering their capacity for efficient information processing and communication [30]. Fatigue adversely affects cognition, including memory, concentration, and decision-making [31, 32].

4.1 Dataset

For this study, a dataset of audio recordings of communications between pilots and ATC was sourced from *LiveATC* audio archives. The recordings were selected on the basis of the crew pairing rosters of an Australian carrier for different days to ensure a representative sample of flight operations. The final dataset covers 239.6 hours of flight time for 350.9 hours of duty time. The study analyzed all the radio transmissions relating to each individual flight, focusing on two key phases, specifically:

- Communications from the time the aircraft begins taxiing to the runway, through take-off, and during the initial climb.
- Communications from the time the aircraft starts its approach, through landing, and until it reaches the gate.

Pilot communication performance was examined based on number of errors, transmission duration, number of words per transmission, and the presence of politeness markers and hesitation markers. The flights were categorized as either Low Tempo (2 flights per duty period) or High Tempo (4 flights per duty period), and as Short Duty Time (less than 8.5 hours) or Long Duty Time (longer than 8.5 hours).

4.2 Results

From a total of 2,021 Pilot-ATC transmissions, 51 pilot transmissions contained an error. The results of the analysis revealed that longer duty times increased communication errors by a factor of 9.2. High flight tempo also increased communication errors, however to a lesser extent, by a factor of 1.7.

Fatigue can result from many factors, and one is time on task (i.e., passage of time [33]). Having established the impact of both flight tempo and duty time on pilot communication errors, it is important to understand the effect of the two conditions relative to 'time on task', as it is possible that the final flights for each condition (flight tempo and duty time) resulted in a higher number of errors.

A Chi-square test indicated that it was not the last flights in either high or low tempo condition which unduly influenced communication errors. On the other hand, a Chi-square test revealed a statistically significant difference between the high and low duty time: using the odds ratio, when pilots are exposed to a high duty time schedule, they are 8.66 times more likely to commit a communication error than when they are exposed to a low duty time schedule.

Although the relationship between flight tempo and errors did not reach the predefined statistical significance level, the results indicate that flight tempo is also an important factor that contributes to fatigue. These results have important implications for the aviation industry. Fatigue from extended duty periods increases pilot communication errors, and communication errors can have severe consequences for flight safety, thus these results highlight the need for effective fatigue management. Implementing measures such as duty time limitations, regular breaks, and sleep hygiene education can mitigate the risks associated with fatigue.

5. Conclusions

This research program has been investigating communication in aviation and the impact of factors on the number and kind of communication errors committed by pilots in general aviation as well as commercial aviation. Linguistic factors such as speech rate and information density impact the comprehension of transmissions for both native and non-native English speakers (NES and NNES). Pronunciation, accent and non-standard phraseology also contribute to misunderstandings. Although NES can find it challenging to limit themselves to a restricted code, the Language Proficiency Requirements should apply to all pilots and air traffic controllers, not just NNES [34]. Communication training should cover standard phraseology (vocabulary, turn-taking, pronunciation) and pragmatic strategies for accommodating to other speakers. In particular, NES pilots and ATC must be trained to understand NNES pilots and ATC. This communication training must include the comprehension of a variety of accents as well as an understanding of the difficulties NNES pilots and ATC may experience when using English.

The presence of politeness markers and hesitations can indicate communication difficulties and can themselves contribute to misunderstandings. Any lengthening of transmissions contribute to cluttering the radio frequency, which potentially prevents the transmission of urgent or distress messages from other stations. As it is not possible to prevent human beings from using relational language, a reduced list of relational expressions ('*bye'*, '*good day'*, '*sorry'*, and '*thanks*') was proposed, which could be taught as part of standard phraseology, along with the standard phrases such as '*Say again'*.

By analyzing the impact of fatigue-inducing factors on pilot communication errors, the latest study provides valuable insights into the extent to which duty time and flight tempo contribute to fatigue, and by extension affect pilot performance. The statistically significant relationship between long duty times and communication errors highlights the need for strict regulations and interventions to manage pilot fatigue.

Together these findings highlight the importance of considering influential factors in pilot communication errors, as they are critical for improving communication protocols between pilots and air traffic controllers and thus enhancing aviation safety.

Future studies should look into the area of high-stress and emergency communication scenarios. Pilots must perform additional cognitive tasks in these situations, therefore, training and safety procedures may benefit from an awareness of how tempo and fatigue affect communication. Studies might look at how pilots handle stressors including workload, time constraints, and environmental factors when it comes to communicating. This would help design focused treatments by offering insightful information on the variables influencing communication accuracy in high-stress scenarios. Future research can also explore the relationship between communication and flight performance to provide deeper insights into the trade-offs pilots make between flying and communicating. Collecting and analyzing data on pilots' flight performance, such as their ability to maintain altitude and heading, could reveal whether communication errors are associated with deviations in flight performance [23].

Future studies should also focus on creating and assessing strategies that increase communication accuracy. This might include policies, processes, and training courses created to facilitate efficient communication in a variety of settings. The usefulness of various treatments, including decision-support tools, communication protocols, and simulation training, in enhancing accuracy and minimizing mistakes in communication might be investigated through research.

Future studies could also examine individual differences in communication. Communication accuracy may be influenced by a variety of factors, including experience, personality traits, and cognitive ability. By taking into account these individual variations, tailored methods may be developed. Research might look at the ways in which individual differences interact with tempo and fatigue to impact communication performance and pinpoint the traits connected to successful communication.

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