"...Say again?..."

Miscommunications in Air Traffic Control

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CONTENTS

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List of Acronyms

AIP	Aeronautical Information Publication
ATC	Air traffic control
BASI	Bureau of Air Safety Investigation
CAIR	Confidential aviation incident report
CAR	Civil Aviation Regulation
CASA	Civil Aviation Safety Authority
CRM	Cockpit (or crew) resource management
FAA	Federal Aviation Administration (USA)
FL	Flight level
HF	High frequency
ICAO	International Civil Aviation Organisation
IFR	Instrument flight rules
MATS	Manual of Air Traffic Services
R/T	Radio telephony
SID	Standard instrument departure
STAR	Standard arrival
TAAATS	The Advanced Australian Air Traffic System
UTC	Universal time co-ordinated
VHF	Very high frequency

Turkish Airlines said yesterday it had sacked two pilots who had a cockpit punch-up over control-tower instructions on a flight between Bangkok and Istanbul. "Are you deaf? He's telling you something and you are doing something completely different", one reportedly told the other. A junior pilot completed the flight.

—Reuters, *The Age*, 7 May 1997.

1. Introduction

This project represents 24 credit points of the Queensland University of Technology's Master of Education (Adult and Workplace Education). The purpose of the project option is to provide the student an opportunity to integrate knowledge from the workplace with core and elective units. Accordingly, I have particularly drawn upon units of language and literacy, legal risk management, and educational research.

The project is an investigation into *miscommunications* between air traffic controllers (ATC) and pilots. Miscommunications may broadly be applied to a range of verbal communications problems ranging from misunderstandings, such as those due to ambiguity, cultural differences, language structure, and so on, to more technical problems, such as microphone "clipping" and over-transmitting of another's radio signal. Studies indicate that miscommunication is a pervasive problem in air traffic control and, although infrequent when considered as a percentage of daily transactions, nevertheless, has been a causal factor in numerous fatal accidents.

The facts about verbal communication come from many different fields of science. The study of verbal miscommunications in the air traffic system is part of the rapidly expanding field of *human factors*. My aim has been to synthesise the knowledge from three fields—aviation human factors, language and communications, and aviation law—and present it in a paper from which I can develop educational resources for air traffic control instructors and team leaders. The relevance or otherwise of the current literature has been filtered by the twenty-five years experience I bring as an air traffic controller, pilot and flight service officer.

1.1 Reason for the Study

The collision between the Pan Am and KLM Boeing 747's at Tenerife in March 1977, which killed 583 people, was a defining event in aviation safety. While there were many predisposing human factors involved, the accident was a tragic lesson in miscommunications. The accident demonstrated that, in the aviation industry, "information transmitted by radio communication can be understood in a different way to that intended, as a result of ambiguous terminology and/or the obliteration of key words or phrases" and that "the oral transmission of essential information, via single and vulnerable radio contacts, carries with it great potential dangers" (Job, 1994:180). Nine months after this accident, the Air Navigation Committee of the International Civil Aviation Organisation (ICAO) took action, issuing three reports and implementing radiotelephony changes in 1984. Two decades later, miscommunication still causes aircraft accidents. As recently as September 1997 in our own region, confusion between the pilot and air traffic controller is considered the most likely cause of the Garuda A300 Airbus crash at Medan, Sumatra, which claimed 234 lives (Thomas, 1998).

My interest in the subject was aroused some years ago when I was sequencing traffic into Sydney. A vector I issued to “Tango alpha delta” (TAD) was acknowledged by “Tango alpha alpha” (TAA) and the wrong aircraft commenced a turn before I could cancel it, fortunately without consequences. Homophony confusion with “alpha” and “delta” occurs occasionally with most controllers, as does a pilot reading back “Flight level two seven zero” when the controller has issued “Climb to flight level two zero zero”. These are also examples of ‘expectation error’ because pilots of both TAD and TAA were expecting vectors, and the crew of a departing jet is expecting to climb higher than twenty thousand feet. But they may also be due to poor pronunciation, poor microphone technique, a distracted, busy crew or a noisy frequency—perhaps all of these.

Amongst controllers there is insufficient awareness of the pervasiveness of the miscommunication problem and its various manifestations. The insidiousness of some of these requires that controllers be provided with a deeper insight into the structures of language and the way which phrases and words can be misinterpreted.

1.2 Scope of the Study

Miscommunications between pilots and air traffic controllers are an international problem. The main source of aviation human factors research is the United States of America which has the world’s largest aviation industry. Yet the question arises just how relevant are US miscommunications problems to the Australian situation? My research indicates that much of it is irrelevant. Hawkins (1993:156) writes:

> It is perhaps a paradox that in spite of universal recognition of the importance of discipline in the use of standard phraseology for safe aircraft operation, the world’s largest aviation country, the USA, is often accused of being one of the greatest offenders. The USA is becoming increasingly isolated in its use of local time instead of GMT [Greenwich Mean Time] and non-metric units in aviation (statute miles, degrees Fahrenheit, inches of mercury, pounds, etc.), complicating international communication....the international pilot flying into the USA will sometimes need to interpret a different form of radio telephony (RTF) from that in use in the rest of the developed world. The English language over Frankfurt in Germany may be closer to international standards, and so more intelligible, than that over, say, Chicago.

The literature bears this out. The use of slang and idiomatic phrases, combined with strong regional accents and the failure to use the standard phraseologies recommended by ICAO, are a feature of Cushing’s (1994) US study. Many of his examples are not applicable to the Australian air traffic system. I have, therefore, made a deliberate effort in this paper to use Australian examples or, where these have not been available, non-US international examples.

We cannot, however, ignore what is to be learned from any aviation accident. Of the 14 key historical events, most of them accidents, that have transformed the US national airspace system since the 1950's, and thereby influenced the Australian system, miscommunications were implicated in five of them (National Research Council, 1997). They were:

- the TWA crash at Dulles in 1974. This accident was caused by communication ambiguity on part of both the pilots and controllers, resulting in the misunderstanding of each other's responsibilities.
- the Tenerife collision in 1977 which demonstrated, amongst other issues, the weakness of voice communications that take place by non-native English speakers.
- the San Diego mid-air collision between a Boeing 727 and a Cessna 172 in 1978. Inadequate phraseologies by controllers were a major factor in this accident which killed 146 people in the aircraft and on the ground.
- the Avianca Boeing 707 fuel starvation crash at John F. Kennedy Airport in 1990. The failure of the Spanish speaking crew to use standard English phraseologies to convey the urgency of their perilous fuel state to controllers resulted in the deaths of 76 passengers and crew.
- the McDonnell Douglas DC-9 and Boeing 727 collision at Detroit in fog in 1990, partly caused by the lack of clear taxi instructions and a failure to transmit a stop takeoff warning..

The review by Gero (1996) includes every mishap on a passenger flight with at least 60 fatalities involving an air carrier of the industrialised world that has taken place since 1950 and every crash causing at least 80 deaths that is known to have occurred. Of the 274 listings, miscommunication between pilots and controllers can clearly be identified as causal factors in 36 of them (13%).

A recent Bureau of Air Safety Investigation (BASI) study into the failure of pilots to comply with air traffic clearances at Sydney determined that, while the rate of incidents based on total movements was small, an average rate of two incidents per week was occurring involving high capacity public transport aircraft (BASI, 1997a). Communications problems were identified as one of the four underlying factors, particularly with foreign crews—the majority of pilots surveyed considered that it was **the** main area of concern**.** Of 175 summary reports of incidents provided to me by BASI, 35 of them (20%) identifiably have miscommunications as causal factors (BASI, 1998a).

Problems of miscommunication are not confined to the aviation industry, of course. For example, lack of a regularised communications system utilising standard, defined terminology was identified as a contributing factor in the nuclear accident at Three Mile Island in 1979 (Barrett, 1982). More often than not, though, there is time for individuals to expose and clarify misunderstandings. The Three Mile Island accident, for instance, unfolded over four days. Time, however, is in short supply for controllers and pilots—it is a time-sensitive environment. They cannot see each other nor each other's actions, so an important means of error detection is unavailable. The rapid trajectories of modern aircraft flight combined with busy sectors and airports provide limited opportunities for aircrew and controllers to step back and reassess situations before they must move on to other tasks.

Communications problems have been studied in terms of their consequences, such as operational errors and accidents, and the results published in aviation safety journals. They can also be described as a concept of information transfer based on the information theory perspective of communications. Perceptual problems occur which lead to misproducing and misunderstanding messages, and linguistic problems are a product of the nature of language itself.

I will look at all these aspects of miscommunications in this paper, mainly from the perspective of the air traffic controller.

"Don't talk to him too much", the captain advised the first officer of the air traffic controller. "He's trying to get us to admit we made a big mistake coming through here".

—cockpit voice recorder transcript,
Lockheed 188A Electra crash near Dawson, Texas, 1968.
(Gero, 1996)

2. The Controller/Pilot Relationship

The air traffic controller plays a central role in the safety of the air traffic system. Amongst other responsibilities, the controller reduces the pilot's workload by taking over the role of detecting and resolving conflicts with other aircraft operating in the same or adjacent airspace, and by providing warnings and advice of known weather hazards and possible military airspace infringements. But in order to understand how miscommunications can occur between pilots and controllers, it is necessary to understand the differing perspectives they each have of the system.

2.1 The Air Traffic Control System

The goal of the air traffic system is to accomplish "the safe, efficient conduct of aircraft flights" and "to maintain a safe, orderly and expeditious flow of air traffic" (Airservices Australia, 1995:F1). As Watkins (1983) has pointed out, air traffic controllers, with their common language, are the crucial link in international aviation. The seamless flight of air traffic across international borders and through jealously guarded sovereign airspace of, often, mutually antagonistic nations would not be possible without the co-ordination of controllers. Whether nationally or internationally, the joint goals of safety and efficiency are accomplished through an intricate series of procedures, judgements, plans, decisions, communications and co-ordinating activities. The public is familiar with the radio communications which occur between pilots and controllers but equally as critical are the co-ordinations within and between air traffic control facilities when controllers 'hand-off' aircraft as they pass from one controller's sector of responsibility to another. "The predominate factor of the ATC system", writes Stock (1993), 'is that it is centred on the controller with all the safety critical decisions emanating from that source". Figure 1 illustrates the central role of the controller.

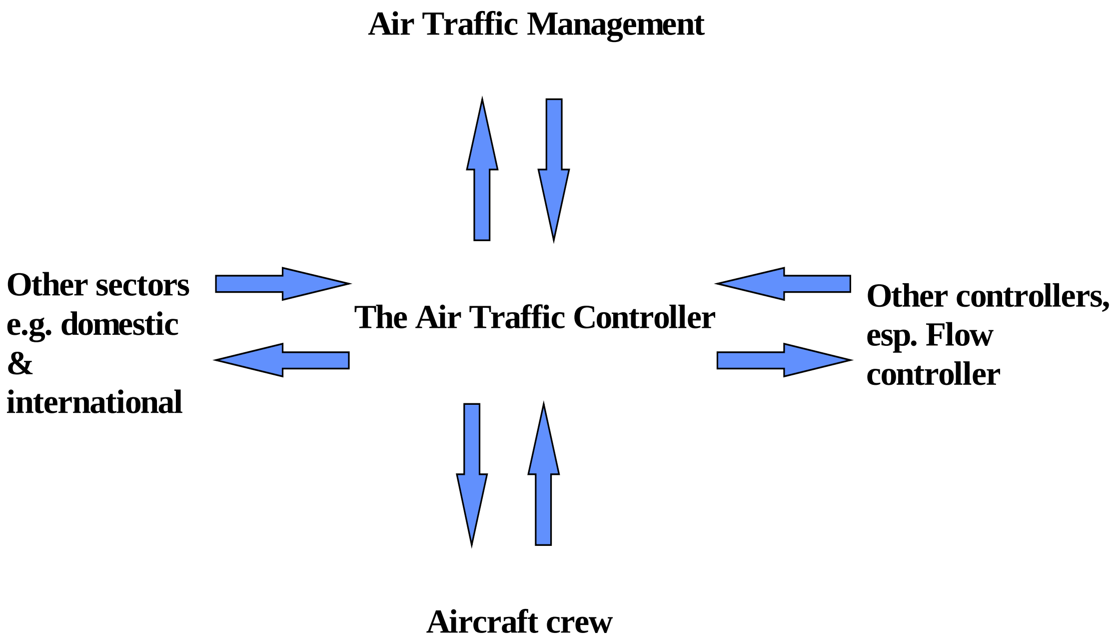

Figure 1: The pivotal role of the air traffic controller in information transfer. *The interfaces shown are those that bear directly on aircraft management in the airspace system.* (Adapted from Billings and Cheaney, 1981:87)

Air traffic control developed from its initial role of communicator and traffic advisor to separation estimator and flight path decision-maker. With the coming of radar, decision-making and judgement functions of ATC increased to the extent that today it has also taken on the role of traffic flow director. The nature of the job and the problems encountered differ with the service being provided. Tower controllers are concerned with separating landing and departing aircraft, the surface movements of aircraft and vehicles, local weather conditions, and the runways in use. They deal with runway incursions, emergency landings and emergency services call-outs, wrong turns, ground conflicts, airfield maintenance teams, and so on. Terminal area controllers, using radar, sequence arriving aircraft into a landing order, accept departing aircraft and establish them on their initial departure tracks, and control all aircraft operating within the vicinity of the airport. They must handle problems such as sequencing disorders, runway changes, aircraft deviations from trajectories (course, speed, altitude), aircraft not on proper approach and departure paths, airspace penetrations, and in-flight emergencies. Enroute controllers deal with aircraft cruising or transiting to or from the cruise conditions and establish holding patterns. Problems of route changes for weather avoidance, flight plan changes, level changes, holding pattern "stacking", climbing, descending and crossing conflicting traffic, and in-flight emergencies must be resolved. Flow controllers analyse the inbound traffic stream, determine the landing order and communicate it to the enroute and terminal area controllers. They must deal with the mix of aircraft types, re-routing, speed adjustments, issuance of holding instructions to controllers, runway changes, and changing priorities due to emergencies or medical flights. In some cases (e.g. Sydney), even before departure, pilots will be told the time that they must arrive in order to be guaranteed a landing 'slot'. Flight service officers provide a traffic information and flight information service to pilots outside of controlled airspace. Air traffic controllers and flight service officers together provide air traffic services.

Such job descriptions fail to convey the complexity of the four-dimensional (space and time) conundrum. Hopkin (1995:153) writes that "air traffic control is complex, more so than it seems at first...To an uninformed observer, most of air traffic control is not inherently meaningful, and it has only become meaningful to the controller because of training". Muller (1996) describes the controller's job as a "strange and specialised one"—on one hand the controllers are expected to apply strictly defined procedures and abide by countless regulations, yet at the same time, they are confronted with new situations requiring substantial flexibility in their response.

There are several distinguishing features to air traffic control:

- *Three-dimensional nature of movement*: The three-dimensional nature of aircraft trajectories can only be displayed on a two-dimensional radar screen or, more awkwardly, on a two-dimensional procedural display console. The controller must think in three-dimensions and predict a fourth.
- *Speed and stress*: Mastering the three-dimensional movement is further complicated by the speed at which it occurs. This reduces the time to recognise, evaluate and react to unexpected problems. It is a matter of reaching quick, workable decisions and not of looking for a perfect solution but finding it too late. Often heuristic thinking is required, not algorithmic.
- *Limited correction possibilities*: There is little leeway for correction. Safety tolerances are usually large but the rapid sequence of events reduces the time remaining to register or correct errors. Controllers must be able to concentrate and react rapidly.
- *Great significance of small errors*: Minor errors or slips can cause serious accidents yet these are difficult to detect. Human error has been called "the relentless threat to aviation safety" (Maurino, Reason, Johnston and Lee, 1995).
- *Constant changes*: The aviation system is in the vanguard of technical development. ATC procedures are in a state of virtually constant change which must be assimilated. Constant retraining, changes to procedures, equipment and aircraft types and performance characteristics require controllers to constantly adapt and be mentally flexible or be overtaken by change.

2.2 The Pilot/Controller Relationship—the "Awkward Alliance"

Ruitenberg (1995) has contrasted the work of pilots and controllers. Although trained to deal with many potentialities, pilots in their normal work ideally should encounter no problems. But the routine work of a controller almost exclusively exists of problem solving, in trying to accommodate traffic safely, efficiently and in an orderly manner in the available airspace. Pilots and controllers have differing perspectives of the conflicting pressures of safety and efficiency. Firstly, a controller has several aircraft to deal with whereas a pilot is concerned with one. The pilot wants to fly the aircraft in the most efficient manner by choosing direct routes or those with the most favourable winds and optimal altitudes. This is not always compatible with the controller's problem of safely managing numerous climbing, descending and crossing aircraft spread throughout a large airspace volume but converging and congregating at a few airports or navigation aids. Secondly, the controller's perspective of efficiency differs because his or her goal is to maintain an evenly spaced flow of all aircraft from airport to airport, even if this means slowing, holding or 'track stretching' aircraft to delay their arrival. The aircraft crew are under pressure to deliver their passengers on time and to ensure that the aircraft is available for its next scheduled flight. The controller tries to maintain sensitivity to the crew's need to avoid excessive and abrupt manoeuvring (for passenger comfort) while achieving safe separation with other aircraft and efficient sequencing.

Besco (1997) has labelled the controller/pilot relationship the "awkward alliance". There are numerous causes for tension, such as the role of the controller as 'traffic cop', the propensity for pilots to bend the truth on time estimates and weather conditions to gain a higher priority and track shortening, and due to perceived status and salary differences. The relationship is unique, he states, because it is not based on emotional attachments nor on political commitments nor organisational pressures. The pilots' convictions of positive expectations are based upon repeated successes of consistent, successful and dependable performance. On any flight, a pilot deals with a dozen or more controllers, none of whom are known personally, and, similarly, a controller deals with dozens of pilots. In order for the system to work, exchanges must be calm and professional. Controllers supply the support that has enabled all skill levels of pilots flying all types of aircraft to safely complete all types of flight plans through airspace and to airports of all complexity levels in all types of weather. Pilots, because they have an incomplete knowledge of the air traffic situation, literally put their own lives and the lives of their passengers in the hands of controllers. They place a heavy reliance on the *voices* of the air traffic control system.

The role of the pilot in the exchange of verbal information differs from that of the controller and is succinctly established in the Civil Aviation Regulation (CAR) 100:

> (1) An aircraft shall comply with air traffic control instructions.
>
> (4) The pilot in command of an aircraft is responsible for compliance with air traffic control clearances and air traffic control instructions.
>
> (Civil Aviation Safety Authority, 1998)

The pilot's task then, except in an emergency, is to receive advisory information, accept instructions, and to act upon them. The pilot must trust a controller's commands because he or she is not, in general, in receipt of enough information regarding the traffic disposition to question them. The pilot provides an element of redundancy by reading back certain instructions, such as clearances, but otherwise provides little information unless first asked for it. But speech between controllers and pilots also fulfils several functions more related to the disciplines of social and personality psychology. As we shall see later, pilots and controllers make judgements about each other based on what is said and how it is spoken.

The teamwork reflected in communication between pilots and controllers is a critical component of the air traffic system because it provides the system's flexibility. Most controllers are not pilots and most pilots are not controllers. Instead of just having impersonal radio contact, it has proved worthwhile for pilots and controllers to observe each other at work. The more they learn about each other, the easier it is to recognise and discuss common interests. Many problems of communications stem from the lack of knowledge the parties have about each other. The closure of many regional control towers, flight service units and briefing offices during the past two decades has markedly reduced the face-to-face contact between pilots and air traffic service personnel.

2.3 Situational Awareness

Situational awareness may be defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995). This obviously differs for pilots and controllers. Situational awareness for pilots refers more to the operation of the aircraft and controlling its flight path trajectory. But because they are required to maintain a 'listening watch' on the control frequency, pilots can build up a less-than-perfect idea of the activity occurring in the airspace sector depending upon factors such as traffic density, airspace size, their time on the frequency and their own workload. However, they often lack enough information with which to evaluate and question controller instructions, even if the instructions are wrong (unless they are obviously incorrect). Billings and Cheaney (1981:90) suggest that this "places a heavy burden on the controller, who in this respect is unprotected by the redundancy so carefully designed into most aspects of the aviation system". But in some circumstances the pilots' listening watch can detect controller errors. This was graphically illustrated by the potential mid-air collision near Mount Isa in 1991 which was averted by the situational awareness of one of the aircraft crews (see appendix 1).

A controller taking over a sector from another will need to build a mental picture of the air traffic before accepting responsibility for the position. Controllers refer to situational awareness in terms of having (or losing) 'the picture' which includes knowledge of the past, present and future situation of not only the aircraft disposition, but also weather forecasts, military airspace status, runway and navigation aid availability, adjacent sectors, degraded modes of equipment, staffing, changes to traffic handling rules and procedures, and so on. Hopkin (1995:58) writes that

> the controller's picture consists of all that is perceived and is meaningful, interpreted in the context of recalled events preceding the current situation, anticipated events predicted from the current situation, and professional knowledge and experience used to maintain control over the air traffic through sanctioned rules, practices, procedures and instructions.

Many ATC positions are staffed by two controllers, especially during peak traffic periods. They work together with one controller handling radar monitoring and communications and the other dealing with flight plan data and co-ordination. Thus a team manages the aircraft of the sector but a single controller usually communicates with the air traffic. This not only divides the task load but, to the extent that tasks overlap, it also provides redundancy in the form of additional eyes and ears to maintain situational awareness.

Redding (1992) discovered that a significant number of speech transmissions by controllers are directed at maintaining situational awareness. It was one of a number of strategies used to monitor the workload and actively update the working memory. The process of issuing instructions and updating the flight strips (upon which are encoded the relevant details of, and subsequent instructions to, each flight), assists the controller in maintaining the picture. However, high levels of communications may not only increase controller workload but may also impact negatively on the controller's ability to maintain situational awareness (Endsley and Smolensky, 1998). Jorna (1991, cited by National Research Council, 1997) found that when controllers spend more than half their time communicating with pilots, they report that their traffic awareness becomes disturbed. When this occurs, the effect of any normally small impact task may affect mental work load and performance. Controllers may use their communications in an attempt to control their workload; slowing down their rate of speech and not condensing their messages may provide them some residual control over their workload, allowing time to keep their flight strips up-to-date and to plan (Hopkin, 1995).

Controllers and team leaders may infer another's planned course of action by overhearing communications directed to others. This pattern of indirect communications and inference is contingent upon controllers developing a 'shared mental model' and allows teams to co-ordinate their behaviour even when task load makes personal communications impossible (Bowers, Blickensderfer and Morgan, 1998). As a flight passes from one sector to another, the controller may need to pass on aspects of his or her situational awareness to the next controller. Prior to Avianca Flight 052's crash near New York in 1990 which killed 73 people, important information about the aircraft's fuel status was passed by the crew to controllers in one facility but this information was lost at the point of hand-off to another. The terminal area controllers then treated the flight like any other when they could have expedited the aircraft's approach (Roske-Hofstrand and Murphy, 1998).

A mismatch of situational awareness between controllers and aircraft crews is a source of miscommunication. An example is the break down of separation between two Boeing 737's in the Cullerin holding pattern (near Sydney) in 1994 where, following control instructions, pilot and controller expectations of aircraft actions differed (BASI, 1997b), exposing a critical gap in procedures and a subsequent refinement of ATC phraseologies. Another is the 1972 crash of Eastern Airlines Lockheed Tristar into the Everglades near Miami which killed 103 people. The controller, watching the aircraft slowly descending, knew that the crew was engaged in determining the status of their nose landing gear, but like the crew, he did not know that the auto pilot had been inadvertently disengaged. He simply asked, "how are things comin' along out there?", an insufficiently precise question to bring the crew out of their mental state. They remained preoccupied with the nose gear indicator and the aircraft descended into the swamp (Gero, 1996).

ATC: *Yankee Kilo, you not have my field in sight?*
G-APYK: *Affirmative.*

—Misunderstanding attributed to language difficulties
and lack of standard phraseologies,
Douglas DC-4 crash,
Roussillon, France, 1967.
(Gero, 1996)

3. The Nature of Language

Communication is fundamental to all human cultures and language is the basis of communication. It is the heart of human information processing, inextricably linked with the cognitive processes as well as with communication. There are the natural languages, such as English or German, and others such as mathematics and computer languages, but each is a system comprising a set of symbols (vocabulary) and a set of rules (syntax or grammar). The importance of language in problem solving should not be underestimated. Inappropriate language structures can make simple problems difficult, or even impossible, to solve. Consider this problem:

47	LXIV
29	XXIX
+ 64	+ XLVII
140	CXL

(from Edwards, 1985.)

There are pitfalls and subtle miscues in the nature of language which can subvert the messages that seem clear to the sender. An understanding of these is critical for pilots and air traffic controllers.

3.1 Phonemes

Any word or sentence may be analysed into a chain of discrete sounds called *phonemes*, the smallest acoustic unit of language that can make a meaningful psychological difference in that language (Ericsson and Simon, 1993). For example, the word *bit* is made up of three phonemes; by substituting the first phoneme */p/* for */b/*, the meaning of the three resulting phonemes is changed from *bit* to *pit.* There is not always one phoneme in the pronunciation of each letter in the spelling. No machine can yet identify the sequence of phonemes in speech nearly as well as the human ear because the same phoneme is not always perceived for a given sequence of sound. For instance a 4-year old girl, a man and an operatic soprano do not emit the same physical sound for */b/*, nor do they sound exactly the same way each time one of them says it, yet we still perceive */b/.* Similarly, we can usually understand different dialects of English even though the actual sequence of phonemes may be different. Americans, for example, pronounce *water* as [WAH-der], whereas Australian pronunciation is more like [WAR-tuh]. Even with three out of four phonemes different, Ericsson and Simon (1993) say, most people will identify a word, especially if the context is meaningful.

Spoken language is more complex than written language because there are no consistent physical boundaries between words or phrases comparable to the spaces in writing. Sometimes there are clear pauses between phonemes but these do not necessarily occur at word boundaries in normal rapid speech (as one may note listening to a foreign language). Ambiguity may occur precisely because such acoustic cues of spacing are absent. (My daughter picked up the following words at weekly assembly in her first year of primary school: "Australians all have ostriches for we are young and free"). Every language uses a different subset of all possible phonemes available and, while there is a high degree of overlap, any two languages contain certain sounds that do not occur in the other, and thus are especially difficult for speakers of the other language (Ericsson and Simon, 1993). We shall consider some aspects of English later.

3.2 Noise

The information theory perspective of communication provides that a sender transmits a signal over a channel to a receiver, speakers are message generators and addressees are passive recipients (Miller, 1951). Mistakes may occur in encoding or decoding the message or may occur while the signal is in transit over the channel. All of these sources of error are called **noise**. The noise of most general interest is random noise which is a "hishing" sound composed of all the frequencies of vibration in equal amounts. It is analogous to white light and so is often called **white noise**.

Irrelevant background noise reduces the sharpness of our discrimination. As the noise increases, the listeners capacity to distinguish differences decreases, which means that the ability to receive information also decreases. The signal-to-noise ratio—the relationship between the loudness of the signal and that of the background noise—is an important concept in understanding communication. The effect of increasing noise is to decrease the area available for communication signals. The human solution to the problem of noise in communication "...has been to use fewer different speech sounds and to rely more heavily upon the sequences in which these sounds are arranged" (Miller, p58)—thus, language. In ordinary speech, we interpret spoken messages by processing visual cues, such as gestures and body language, to supplement verbal information. The potential for miscommunication between pilots and controllers, who cannot see each other, is great because all non-verbal cues are absent. Figure 2 illustrates the role that visual cues play in overcoming noise by adding to the auditory information.

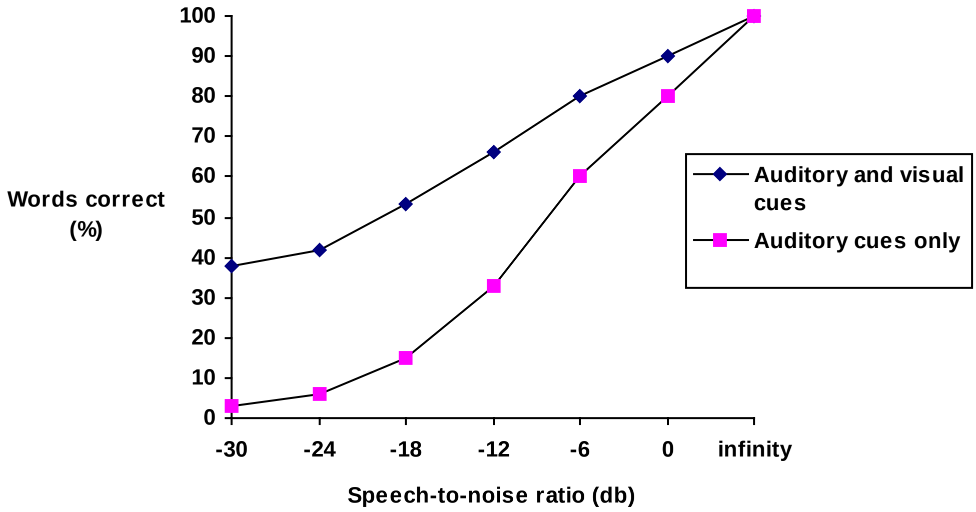

Figure 2: Intelligibility of words when perceived with and without visual cues from observing the speaker. (From Hawkins, 1993:162.)

Spoken speech can be followed as fast as 400 words per minute (about 30 phonemes per second). This is much quicker than the fastest rate we can pick out individual sounds in any other sequence of sounds; thirty separate sounds of anything else except natural language is perceived as white noise (Ericsson and Simon, 1993).

Perhaps the most persistent noise controllers and pilots have to compete with is the sound of another person's voice. It seems that it is relatively easy for a listener to distinguish between two voices, but as the number of voices increases the desired speech is lost in the general jabber, even though the overall intensity of the masking speech is held the same. With several voices a continuous masking signal is produced and the babble of four or more voices will drown out the desired voice as effectively as any kind of other noise (Miller, 1951).

Another form of noise is equipment noise. Electrical equipment has 'line noise' and radio is affected by atmospheric conditions. These may be sufficient to interfere with communications by masking words or phonemes.

3.3 Intelligibility

In conversation we are bound by syntactic rules so that verbs, nouns, adjectives, and so on appear in certain standard and expected patterns. Often, more words are used in speech to encode a message than are theoretically necessary—this is called **redundancy**. Its advantage is that parts of the message may be lost or distorted but the message will still be intelligible because of the extra words. The receiver supplies any missing portions on the basis of the **context** of the sentence and clues derived from the surrounding words. Once the basic pattern of a sentence is revealed, the range of possible words that can be substituted into the pattern is greatly decreased.

Listeners are able to discriminate more effectively among a small number of possibilities than among a large number. It is for this reason that ICAO standardise a small vocabulary and insist upon stereotyped procedures for all air traffic communications.

The accurate perception of a spoken word depends not only upon the acoustic characteristics of the word, but also upon the **expectations** in which that word occurs. The Articulation Index is a measure of intelligibility and is simply "the percentage of spoken material of any particular type which is understood by a listener" (Hawkins, 1993:164). In figure 3, when restricted vocabularies were used, the listeners knew exactly what alternatives to expect. As the size of the test vocabulary increased, it was necessary to increase the intensity of the speech relative to the noise in order to maintain a given level of accuracy.

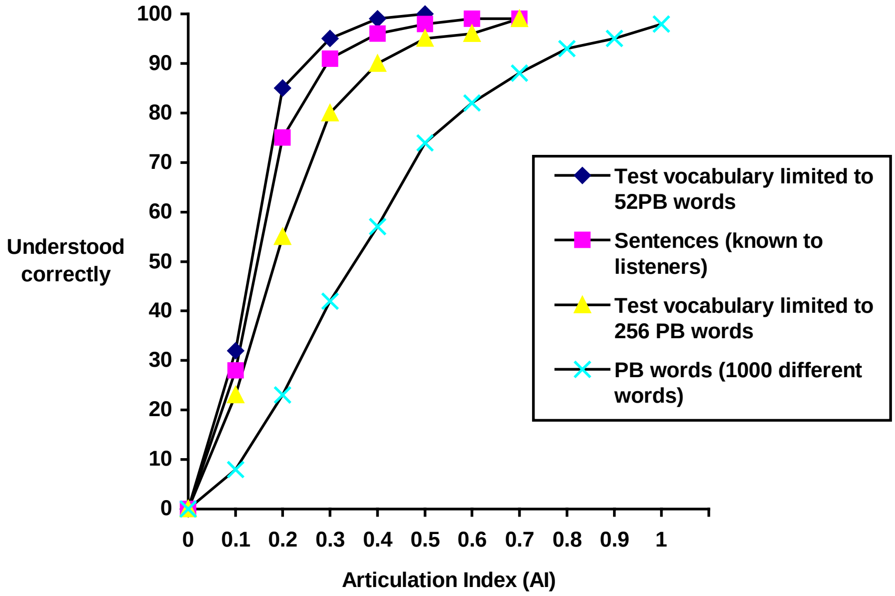

Figure 3: The relationship between the Articulation Index (AI) and the intelligibility of various types of speech test materials composed of phonetically balanced (PB) words and sentences. (From Hawkins, 1993:156.)

The value of sentence structure as context for the correct perception of words is illustrated in figures 4 and 5. When the key words in a sentence are taken out of context they become much harder to hear. And because language decoding is continuous, we often have to 'backtrack' in order to understand the meaning of a sentence.

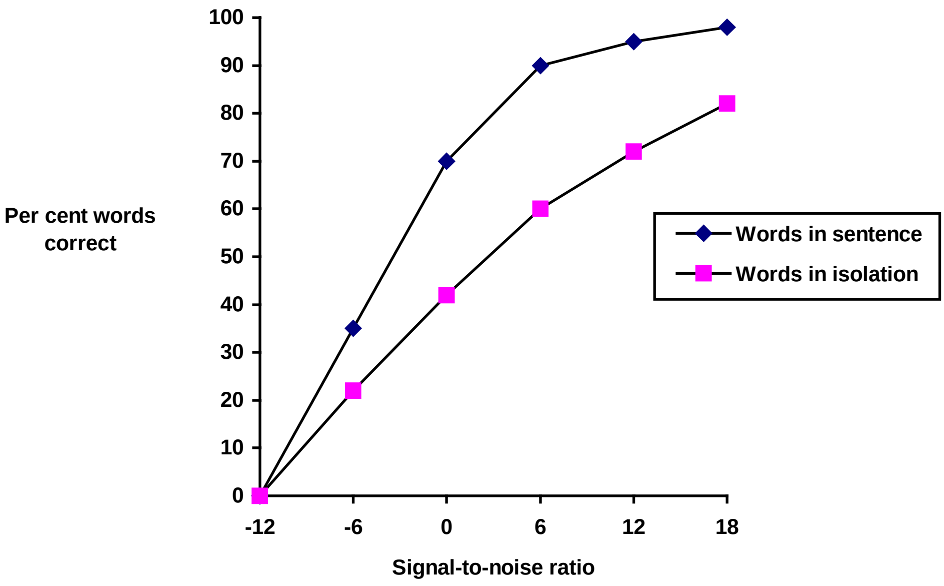

Figure 4: The effect of the sentence context upon the intelligibility of words. (From Miller, 1951:78.)

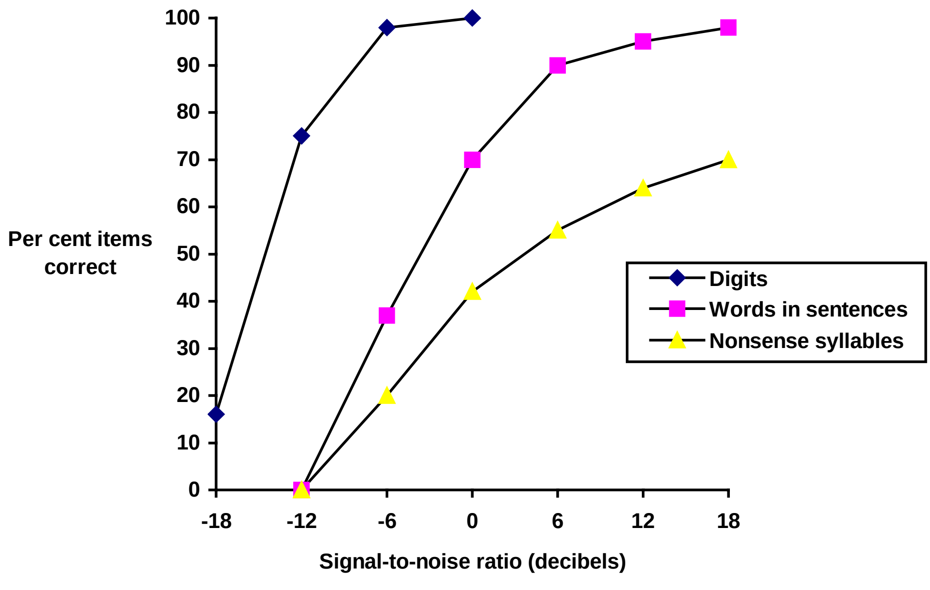

Figure 5: Intelligibility of words in tests. *In order to get 50 per cent of the items correct, the nonsense syllables had to be 17db more intense than the digits*. (From Miller, 1951:75.)

Even if we miss a word or two, we can still construct what the speaker said based on the usual context of the situation. Context often makes much of the semantic content clear: we use our knowledge of the world to understand language.
Deciding which word to insert into a broken communication requires:

- knowing the probability of encountering that word in speech (or print);
- for many words, knowing the type of words most likely to be associated with the word;
- knowing the limitations imposed on the use of the word according to variations in function and situation;
- knowing the syntax associated with the word. (Richards, 1985)

Thus, frequently used words are more readily perceived than infrequently used words and some words are intrinsically more audible than others. Unfortunately, the vowels have more power than the consonants but it is the consonants that are more critical to the correct interpretation of speech. The vowels 'a,e,i,o,u' are distinctly different when compared with the consonants 'b,p,t' and 'm,n', yet the communication '-a- -oe -i- -a-?' is more difficult to interpret than 'Wh-t d-s th-s s-y?'. Miller discusses various methods of "butchering" speech and concludes that "the ear is very facile in patching together the interrupted fragments of speech and in reconstructing the whole message" (p71).

We can summarise the role of the listener and say that

> perceiving speech is not a passive, automatic procedure. The perceiver contributes a selective function by responding to some aspects of the total situation and not to others. He responds to the stimuli according to some organisation that he imposes upon them. And he supplements the inconsistent or absent stimulation in a manner that is consistent with his needs and his past experience. (Miller, 1951:79)

This *expectation* aspect of speech is important in understanding miscommunication in the air traffic control system.

3.4 Speech and Memory

The perception of useful ATC information is confined to the senses of sight and hearing. Communications between pilots and controllers are a major factor influencing controller mental workload. Air traffic controllers frequently deal with information overload. Selectively switching one's attention between competing information sources, visual and auditory, is a basic skill that a controller must develop in order to stay ahead of the situation and not 'lose the picture'. The need to selectively attend and divide one's attention is due to the limitations of working memory.

Working memory represents a critical component of communications. It temporarily retains information which is either verbal or spatial. Verbal working memory is the 'rehearsable' memory for sounds, such as digits and words, that a controller uses when receiving a request or readback from a pilot. Information in working memory is interpreted on the basis of information stored in **long-term memory,** which retains the less dynamic aspects of the controllers environment, such as airspace knowledge, air route structure, aircraft performance, procedures, and standard phraseologies. Routine actions, decision-making and planning processes draw heavily on knowledge in long-term memory, and strategies (or heuristics) picked up by experience or observation of others are stored there. The exchange of information between the working and long-term memories is “the process of comprehension that provides a mental picture of the situation confronting the controller and underlies the controller’s situational awareness” (National Research Council, 1997:94).

Because working memory is heavily involved in the processing of speech, it is limited by long messages, which are often misunderstood, and background noise, particularly, as noted, other verbal activity. This limitation occurs whether the speech is in the immediate environment or the controller trying to remember a communication while concurrently speaking or listening. A controller can easily talk to a pilot while scanning a radar display, but cannot easily talk while listening to another controller. The length of the message may induce errors: having to produce two kinds of response to the same message increases the chances of forgetting to do one or the other response, yet if a controller presents a pilot with two short messages, this also can lead to forgetting (Morrow and Rodvold, 1998). Working memory also suffers if it must retain items that are similar to each other, such as similar aircraft callsigns, names or acronyms. Where control positions have two or more frequencies, the controller can generally listen to only one transmission at a time with any accuracy and recall of the information. Experiments show that switching between incoming auditory information can take place but that only one message at a time can be listened to precisely (Roske-Hofstrand and Murphy, 1998).

The problem for air traffic controllers is not so much the quantity of information being received, although this is considerable, but rather the lack of influence they have over the timing of these events to which they must promptly respond, and the little time available to mentally process them while they remain in the working memory. The number of communications events adds much to the complexity of controllers information processing tasks. Much voice communication is ‘expectation-driven’ which reduces the load on working memory until unfamiliar material (such as strange names, non-native language) or long communication strings must be retained for even a few seconds before being translated into action (National Research Council, 1997).

A further complication arises for the radar controller: **visual dominance phenomenon** occurs primarily when auditory information competes with visual information (Roske-Hofstrand and Murphy, 1998). Visual stimuli offer good referability through continuous presentation but auditory stimuli are transient. Visual stimuli are spatial and their display occupies space, but auditory stimuli are temporal in that their presentation occupies time. Visual stimuli can be presented sequentially or simultaneously, but auditory ones must be sequential. The dominance of visual stimuli over the auditory means that a controller concentrating on a visual display of, say, aircraft rapidly converging , may not hear a concurrently presented auditory signal such as the sound of a minimum safe altitude warning alert or an aerodrome terminal information service change.

3.5 Expectation

Expectations influence perceptions and therefore underlie many other potential errors in voice communications. We hear what we expect to perceive and this allows the perception in working memory of routine and expected events to proceed rapidly and with minimal effort. Their importance in our lives cannot be underestimated:

> Expectations are powerful determinants of both everyday experience and professional decision making. Expectations are hypotheses about the future based on experience, i.e., expectations are derived from our stored patterns, scripts, or schemas. (Roske-Hofstrand and Murphy, 1998:101).

Whilst such expectations can be a useful tool to enhance learning, they are a source of vulnerability. Under conditions of high workload or distraction, events can occur which are other than as expected. Expectation errors may be caused by fatigue and information overload. Noise can interfere with signals so we hear what we expected to hear, not what was said. The expectation of an instruction can prime a pilot to mistake a different communication for the anticipated one. Brookes (1996:22) provides an example of the problem:

In May 1995, a Lufthansa Airbus A300 was taxiing at Heathrow. An amended standard instrument departure (SID) with an altitude restriction was being passed to pilots by the tower controller due to special flights in the area. It was not known when these flights would finish and when normal SID's would be resumed; the crew might receive either. The Lufthansa crew noted that the controller passed the amended SID to preceding aircraft before instructing them to line-up, then issued the take-off clearance. The Lufthansa crew was not given the amended SID prior to the line-up instruction. As the aircraft took off, the pilots saw two vehicles and a taxiing Boeing 747 crossing the runway. They elected to continue with the take-off, passing safely over the obstacles, but commented to ATC that to be cleared for take-off with ground traffic crossing the runway was not a good idea. The controller advised them that a take-off clearance had not been issued. A review of the ATC tapes revealed that after the A300 had lined up, an amended SID had been issued. The crew expected to receive a take-off clearance after line-up so had taken off.

That two pilots were mistaken demonstrates that expectancy is very high in the air traffic system. Unlike in social conversation, a pilot hearing a distorted control message knows that the controller would not say something meaningless or trivial. The pilot tries to fill the gaps and hears the message he or she is expecting.

The other aspect to expectancy is that poor communications by controllers leads to differing expectations. In a review of Swedish incidents Haglund (1994:151) commented that the air traffic controller "expects, often as a result of indistinct or incomplete phraseology, that a pilot will act in a certain manner. The controller therefore neglects to take measures that would ensure the pilot to perform in the manner assumed by the controller". Expectation, then, is a double-edged sword: poor phraseologies by controllers may cause expectation errors, but good phraseologies may not necessarily prevent them.

3.6 Efficient Communication

The aim of communication is to achieve a certain effect on the receiver. Successful communication takes place when the intended result is achieved. Communication can be viewed as the means by which pilots and controllers jointly accomplish operational goals. Hawkins (1993:152) calls efficient communications the "lubricator of the system"—without it the airways would grind to a halt because the system's safety is reliant upon verbal communications.

To communicate effectively, three conditions must be met (Brauner, 1994:31):

1. the sender must be sure of what he or she wants to achieve;
2. this intention should be recognised by the receiver;
3. the receiver should understand the personal advantage in behaving according to instructions.

Thus, communication always involves agreement on common goals. This does not imply a necessarily harmonious alliance because an agreement may be forced upon the parties in question, resulting in at least one of the parties having to compromise their position. The dispute remains unresolved and may flare again. If, however, the agreement comes through an understanding of the other's goals and needs, communication is likely to be effective.

In air traffic control, communications effectiveness depends upon shared assumptions or a shared mental model or shared situational awareness between the sender and receiver. Pilots and controllers, we noted earlier, have differing perspectives of the aviation system. They have an overlapping mental model, not a coincidental one. Thus good communications are necessary to overcome misunderstandings and to expose false assumptions. For example, a pilot will probably be unaware of the other traffic that influences a controller's decision to issue inconvenient or complicated instructions. In such cases, controllers will, time permitting, try to include the pilot in the decision-making process by explaining the reason for the instructions (colloquially known as "wording up the pilot"). The pilot is more likely to support the final decision and it improves the crew's situational awareness.

Never-the-less, it is important that communication by controllers be understood, not as a mere transfer of information, but as a means of achieving a certain mode of behaviour from the pilot. This carries the authority of CAR 100. The communication is command oriented and reflects the central role of the controller implementing his or her plan to resolve airspace problems. Thus, during routine operations, the controllers message is nearly twice as long as the pilots because the controller issues instructions which the pilot acknowledges (Roske-Hofstrand and Murphy, 1998).

Communications between controllers differs in that they make inquiries, observations and answer questions in order to develop and maintain a shared mental picture. The hierarchical communications structure established by the Civil Aviation Regulations between pilots and controllers does not exist between controllers. When the traffic handling plans of two adjacent controllers conflict, they must quickly negotiate a satisfactory resolution based on traffic priorities. Studies indicate that the best performing radar controllers make significantly more enquiries about the control situation (Fisher and Kulick, 1998). These controllers make more acknowledgements of the information received and indicate more response uncertainties. Their technique appears to be one of using team communications to gather information to update their situational awareness and to respond to and check on the information that is being passed to them by other controllers.

3.7 Qualitative Information in Speech

Two kinds of information are contained in speech: quantitative information and qualitative information. Essentially they distinguish what is said from how it is said. **Quantitative information** includes an aircraft's speed, level, heading, position, and so on, and can be communicated in writing or digitally and displayed. **Qualitative information** includes voice quality, formality, degree of stereotyping, pronunciation, accent, pace, pauses, level of detail, redundancy, courtesy, adherence to standard phraseologies, acknowledgement and so on (Hopkin, 1995; National Research Council, 1997). Pronunciation alone communicates information such as the speaker's geographical origin, social class and education. This information is sensed and processed based upon the listener's experience. Hopkin considers that the amount of qualitative information that pilots and controllers obtain from speech, and the judgements which they then make from it, has been seriously underestimated.

> Rightly or wrongly, pilots make judgements about the competence and reliability of the air traffic control service they are receiving and request clarification, confirmation and supporting evidence accordingly. Similarly, controllers make judgements about individual pilots based on what each says and does, and they may check more frequently that their instructions are being obeyed or require more transition states to be reported if they believe that a pilot is inexperienced or unfamiliar with local procedures. (Hopkin, 1995:27)

Controllers and pilots believe that speech conveys useful information about individual confidence, authoritativeness, competence, professionalism, irritability, uncertainty and unease. They then use this information as a basis for decision-making and acting. For instance, given the right degree of situational awareness, controllers and pilots can obtain important cues from the degree of proficiency they each display in radio transmissions and will adjust the complexity of their instructions or requests accordingly; a controller may talk more slowly to what he or she believes is a trainee pilot; a controller will enunciate more carefully for a pilot with a foreign accent; a pilot will omit pleasantries to a controller who sounds exceptionally busy. But qualitative information is not beneficial if, for example, it leads to a pilot not pressing a point with what he or she perceives to be a busy or flustered controller. Not long before the Boeing 707 crashed after fuel exhaustion, Avianca Flight 052's second officer said of the New York Approach controller, "the guy is angry"—a qualitative judgement, not necessarily correct, and with what affect on his subsequent decision-making and actions?

The soundness of these judgements has not been tested but is likely to be studied in the near future. The question to be answered is: can qualitative information in speech be safely eliminated because it is not essential for system safety or efficiency, or, are the judgements made from them sufficiently incorrect that the system would be better off without them?

Hopkin (1995) also points out that communications and phraseologies are observable means that permit management, team leaders and others to judge the professional competence of individual controllers and on lapses in that competence. As we shall see, it also has a cultural dimension.

Speedbird Nine: *Mayday, Mayday, Mayday—Speedbird Nine. We have lost all four engines. Out of [Flight Level] 370.*
Jakarta Control*: Speedbird Nine, have you got a problem?*
Speedbird Nine: *Jakarta Control—Speedbird Nine. We have lost all four engines. Now out of 360.*
Jakarta Control: *Speedbird Nine—you have lost number four engine?*
Speedbird Nine: *Jakarta Control—Speedbird Nine has lost* ***all four*** *engines, repeat* ***all four engines!*** *Now descending through Flight Level 350!*

—British Airways B747 emergency
(flight through volcanic ash)
Java, 1982.
(Job, 1996)

4. Voice Communications in the Air Traffic System

Air traffic control is based upon the processing of information provided in aural, visual and written form. Of the plethora of skills needed by a controller, the two most important are the ability to communicate and the ability to receive and disseminate information. Information obtained through speech is universal: every ATC job requires some verbal communication by the controller, and includes information spoken to the controller by pilots or other controllers. Nearly all the highly dynamic information, such as clearances, traffic separation and avoidance information, weather information and flight plan changes, is currently transferred by means of voice over radiotelephone.

Speech has great flexibility as a means of communication. The apparent ease with which we communicate in daily life—and the general lack of serious consequences when we miscommunicate—tends to disguise the complex process which can cause problems in the aviation system. In air traffic control, much of the richness of English and the flexibility and utility of speech must be curbed in the interests of standardisation, intelligibility, completeness and the prevention of misunderstanding and error. The resultant ATC speech is often unintelligible to the outside listener because it is a lexicon of abbreviations, acronyms and jargon; even if the words can be made out, they do not make much sense without a knowledge of the air traffic control task. The correct interpretation of this speech relies heavily on the experience and training of pilots and controllers. A critically high information element in a small part of the message between a pilot and controller may be lost easily because, as we have seen, speech is subject to some characteristic sources of misunderstanding and confusion that are independent of its content.

Some of the problems are associated with human attributes, such as accents or non-native speakers of English. Cultural sensitivity is a rising area of concern as the industry grows in Asia and Central and South America. Technical issues are more straightforward such as those of frequency failures, high background noise in busy ATC environments and measurable speech distortions that characterise communications equipment, such as headsets, telephones, intercoms and loudspeakers.

4.1 Standardisation in Communications

Hamilton (1991) has written, "a system is only as reliable as its weakest link and it can be said with reasonable confidence that the weakest link in the aviation system is the human component". Humans contribute the flexibility necessary to the air traffic system but human performance is erratic. Controllers and pilots make mistakes and, due to the dynamics of the system, these mistakes can be serious. The means used to protect pilots and controllers from human error and incorrect and inconsistent system operation is the standardisation of procedures and communications. There is an argument for having stricter procedures for communicating information than those for operating hardware, says Byron (1992), since the human involvement in communication is greater and, in air traffic control, requires 'double-handling' where errors can occur at either end.

The content, structure, dialogues, vocabulary and sequences of spoken air traffic control messages have been standardised by ICAO to avoid ambiguity and potential sources of error. The phonetic alphabet was adopted from the North Atlantic Treaty Organisation (NATO) and, according to Hawkins (1993), it was developed with the requirement that words with Latin roots should be given preference in developing the standard phrases. ICAO PANS-RAC and Annex 10 set out the ICAO standards for number and alphabet pronunciation, word usage and message phrasing. In Australia they are given effect by CAR 82 which states that CASA "may give directions in relation to the words and phrases to be used in communicating with, or in relation to, aircraft, using radio communication systems..." (CASA, 1998), and published for controllers in the Manual of Air Traffic Services (MATS), and for pilots in the Aeronautical Information Publication (AIP).

The communications technique required by ICAO is a four-step 'confirmation/correction closed-loop':
1. the sender transmits a message;
2. the receiver actively listens to the message;
3. the receiver repeats the message back to the sender;
4. the sender actively listens for the correct readback.

The system's safety margin depends on all four elements being performed correctly. The standard format makes the tasks of issuing and responding easier because the parties are in a 'primed' state of mind. It attempts to compensate for distractions and the ambiguity of context by requiring certain actions by controllers and pilots to ensure that the intended meaning of their message has been understood. It is designed to compensate for the fallibility of memory. But miscommunication can occur at each step due to noise, the use of non-standard idiomatic phrases, paraphrasing, slang, regional accent or when the listener's expectations influence what is heard. Errors generally occur in step 1 due to these linguistic traps. Steps 3 and 4 are the defences in depth but will not prevent error if acknowledgements become so routine that they are not actively listened to. Readbacks are not always accurate and controllers sometimes fail to detect the inaccuracies.

Non-routine communications occur when pilots and controllers focus on the communication itself to resolve misunderstandings (Morrow and Rodvold, 1998). These are ‘multi-loop’ transactions because more than one exchange is required to understand the message. Although they lengthen communications and reduce efficiency, these non-routine communications are critical to air safety. Misunderstandings which were not clarified have contributed to major accidents, including Tenerife where the pilots were unsure of which taxiway to take.

The demands on controllers while communicating cannot be ignored. Communicating with pilots places demands on controllers’ information processing resources. Controllers must filter the radio communications by focused attention (distinguishing the signal from noise) and selective attention (sampling the sources to select those directed to them). It takes time to deliver instructions and listen to the pilot’s readback. Controllers must focus on the pilot’s speech to acquire the message, often against a noisy background, integrate this message with their knowledge of the flight and traffic situation, and, in the case of a pilot request, evaluate it and formulate a response. Pilot communications may be considerably less standard than that of controllers because there are considerably more pilots and the level of skill, standard of training, and fluency in English and phraseologies is far more diverse. Frequency congestion can cause long waiting times for access, and interrupted or over-transmitted messages may have to be issued again. This will have measurable affects on controller performance which cannot be alleviated through better training (Roske-Hofstrand and Murphy, 1998).

The parallel processing involved when communicating and continuing to track and separate aircraft, and the linear, serial nature of speech communications, imposes time constraints, resulting in pressure to save time by keeping messages brief. The limited vocabulary, along with the standardised format and syntax of ATC language, is designed for both brevity **and** clarity—a fundamental conflict. As Hawkins (1993:169) notes, “in other fields, such as law and government, messages are lengthened to ensure they are unambiguous. In aviation, phrases are being shortened, due to time pressures, but they still need to be unambiguous”. Part of the problem, Hopkin (1995) suggests, is the aviation industry’s propensity to use everyday words and assign them narrow, specific meanings. Other professions, such as science and medicine, use neologisms—new words or phrases—in order to express ideas with greater precision. In normal conversation, a word will have a slightly different meaning to different people (sometimes referred to as ‘slippage’) so the danger in using everyday words to mean specific things is that misunderstandings may occur. The problem is not confined to the aviation industry. Hayward (1997) reports that when the Japanese banking power houses Dai-Ichi and Nippon Kangyo merged to form Dai-Ichi Kangyo, a team of managers from both sides were assigned the task of developing a 200-word glossary explaining what each bank meant when using exactly the same words.

The importance of a distinct and fixed phraseology in order to verbally express one’s decisions and actions constitutes a key behaviour for aviation industry personnel.

Controllers and pilots are human, each with individual thought processes which influence the way they interpret phrases and expressions. The ICAO-standard ATC phraseologies are designed to minimise confusion but such a system is only effective if used in every instance and, even then, miscommunication may occur. The minor differences between ICAO and Royal Air Force phraseologies led to a Learjet crash in the UK in 1996 (Morrow, 1997).

4.2 English—the International Language of Aviation

The post-World War 2 civil aviation industry was dominated by the English-speaking nations, their aircraft manufacturers, and their pilots. Success of international civil aviation depended upon standardisation of aviation procedures, of which communications was one. Uplinger (1997) explains that in formulating its policy for air traffic control language, ICAO recognised that many countries would wish to use their own languages and so recommended communication in the language normally used by the station on the ground. Somewhat equivocally, it recommended that English be available at all control facilities serving international traffic—a provisional measure until a more universal aviation language had been developed. Thus, while English is not mandated by ICAO, fifty years on this ambiguous situation has resulted in the *de facto* use of English as the international language of air traffic control. English became the *lingua franca* for international aviation simply on the basis of economic, geographic and cultural dominance. This process continues today as Russia and China, which had not previously had reason to adhere to the English language policy, launch major efforts to improve and expand the English language skills of their controllers and pilots in a desire to open their airspaces to more commercial traffic (Goertz, 1997). In Australia, CAR 184 (2) requires that all ATC communications be in English unless arrangements have otherwise been arranged.

The ICAO spelling alphabet was the product of extensive research to choose a set of words which would sound as different from each other as possible when spoken by people whose native language was not English over noisy and degraded communications channels (ICAO, 1993). Even so, Stewart (1992:56) writes that "learning the form of R/T [radio telephony] terms and phrases and adapting to the many speech peculiarities of countries is something like learning another language. Sometimes there is difficulty in understanding the plain English used, especially in such countries as Japan where pronunciation is a problem". A poor understanding of English by the Kazakh Ilyushin-76 crew has been repeatedly cited as having contributed to the worst-ever mid-air collision when the freighter collided with a Saudi B747 over India in November 1996, killing 349 people (Morrow, 1997). There are many different versions of English so the problems of three different nationalities speaking English to each other are obvious.

The level of English training that pilots and controllers require is currently the matter of some dispute. Goertz (1997) feels that, because much of the critical information that is passed is based on numbers and letters (e.g. callsigns, altitudes, flight levels, radio frequencies, vectors, runways, wind velocities, etc.), a controller with a good command of the ICAO phonetic alphabet and a limited number of standard phrases can avoid many ATC/pilot miscommunication problems. But Uplinger (1997) argues that the mastery of a specialised terminology is insufficient to avoid ambiguity. Developing functionality in a foreign language is a difficult task, she says, and a pilot or controller who knows 200-300 English ATC terms may have little functional ability. Uplinger cites the case of the crash of American Airlines Flight 965 near Cali, Columbia in December 1995. The Cali controller complained that he did not have adequate English skills to resolve questions when the crew made illogical statements about the aircraft's position. The Boeing 757 killed 160 people when it flew into a mountain.

The acquisition and use of language skills is complex and involves learning grammar, pronunciation, intonation and usage. It extends to

> the gleaning of further information from its nuances and subtleties, such as pauses, hesitancies, slight variations in phraseology, excessively pedantic or rigorously stereotyped message formats, acknowledgements that seem to lack understanding, minor flaws in repeated messages, and other signs of unsureness or lack of confidence in the speaker or listener. (Hopkin, 1995:131)

Apart from the phonemes mentioned earlier, Ericsson and Simon (1993) discuss the class of important cues *stress, pitch, pause* and *intonation* in the English language. The most important is stress which can often make the meaningful difference between two words. For example, IN-sult and PER-mit are nouns, while in-SULT and per-MIT are verbs—the phonemes are the same but the stress distinguishes the meaning. Differential stress in a sentence may distinguish an adjective-noun combination and a proper name; e.g. George lived in the white house. Compared with many languages, English has a high degree of differential stress, the application of which is determined by some fairly regular, though highly complex, rules. It is a very difficult aspect of English for speakers of such languages as French and Japanese where differential stress is much less marked. Pitch and tone make no difference within a given syllable in English and most modern European languages, whereas in so-called non-tonal languages as Chinese and Vietnamese, pitch can distinguish one word from another. In Mandarin, *he* can mean "drink", "river", "and", "box", or "congratulations", depending on whether it is spoken with a flat, rising, falling plus rising, or falling tone. Pitch is important in English insofar as it combines stress to produce characteristic intonation patterns to state, question or exclaim an utterance. These patterns are so strong that even a declarative sentence becomes a question if spoken with a rising intonation: *The aircraft is taxiing?*. Stress on a particular word can radically alter the meaning of a sentence:

a. Drive to the *park* (not city)
b. *Drive* to the park (don't walk).

The irregularity of English adds to its complexity so that even a simple pause between syllables can change the meaning of a sentence. For example, a pause after the */t/* determines the sequence of phonemes as either *night rate* or *nitrate*. Such is the flexibility of the language that two phrases with almost identical structures and words can convey entirely different meanings. Morrow (1997:22) uses this example:

Concorde flies like an arrow but fruit flies like an apple.

This flexibility is incompatible with the need for unambiguous communication in air traffic control.

Obviously the potential for serious misunderstandings between controllers and pilots is high during international aviation communications. Uplinger (1997) recommends learning special terminology in the context of the general language in which it is used. Thus ATC phraseology should be taught to those who have a relatively advanced knowledge of English. Only then would they have the ability to avoid ambiguity or the ability to clarify and resolve ambiguous situations. The French 3-year air traffic control course is completed in an English-speaking environment (Casanova, 1992) while Hong Kong controllers are regularly sent to England or Australia to improve their English skills and confidence (Parker, 1997). Following several highly publicised incidents, including a near miss by an Aerolineas Argentinas aircraft with the World Trade Centre in New York, the Federal Aviation Administration (FAA) recently proposed that ICAO establish English language standards; surprising perhaps, because, as we have previously noted, the American system does not conform with ICAO standards of telephony. In establishing an English training course for Russian controllers, writes Goertz (1997), instructors intended using the American model of English. But following research which indicated that much of the future growth of aviation would be in developing countries, the course was constructed around standard ICAO.

Those whose native language is not English are at a disadvantage during non-routine communications. In these situations, constant vigilance of spoken words and context is required of pilots and controllers to ensure that each understands the other.

4.3 Canada and the Issue of Bilingual Air Traffic Control

The almost casual way in which English has been chosen as the language of international aviation can be considered culturally offensive and is construed by some as cultural imperialism (Morrow, 1997; Sprogis, 1997). Nowhere has the issue been more fully explored than Canada where, in the 1970's, a Commission of Inquiry into Bilingual Air Traffic Services was established in Quebec to resolve the right (or otherwise) of French Canadians to have air traffic control conducted in their own language. The use of French had been rejected by English-speaking controllers and pilots as a reduction in safety because pilots would be unable to maintain situational awareness if they did not understand what other pilots and controllers were saying. The controversy was heightened in 1976 when a British Airways Hawker Siddeley Trident and a Inex Adria Aviopromet (Yugoslavia) McDonnell Douglas DC-9 collided in mid-air near Zagreb, killing 176 people (Gero, 1996). It was soon learned that the Yugoslav pilot and controller conversed in Serbo-Croat which prevented the British pilot from being aware of the danger. Perhaps if both pilots had been using the same language, either one might have detected the controller error or taken evasive action. (Poor phraseologies by pilots and controllers were also implicated in this accident—Stewart, 1986).

Bilingual IFR (instrument flight rules) Communications Simulation Studies (BICSS) were conducted to gather data on communications characteristics, communication errors and losses of separation. These included the duration of controller messages and latency—the time required by controllers to respond to messages. Communication errors included those which occurred on both bilingual and unilingual days, and those which occurred only on bilingual days, such as a controller addressing a message to a pilot in the wrong language. Average transmission times were found to be slightly longer in French than in English. Bilingualism caused no loss in system efficiency (i.e. arrivals and departures). However, there was a statistically significant increase in errors identified on bilingual days compared with unilingual days. The difference was caused by false starts, where a controller began a transmission in one language but corrected himself before he had finished, and language changes, a more serious error where a controller completes a transmission in the incorrect language, receives no reply, and so must begin again. The researchers found the normal rate of miscommunication disquieting:

> Participants in the simulations, especially pilots, were surprised and concerned by the high error rates in the exercises. In order to determine whether these were representative of the real world, the project team compared samples of several hours of unilingual control tower tapes and of unilingual simulation exercise tapes and found that the incidence of controller and pilot errors was indeed comparable. (Borins, 1983:203)

There was, however, no statistically significant difference in the rate at which losses of separation between aircraft occurred.

The BICSS team also studied the role of the listening watch. Of 97 errors, 32 were detected by pilots listening on the frequency. The listening watch was more effective in the enroute environment than in the terminal area because pilots are tuned into the enroute frequency for longer and are not as occupied with controlling the aircraft. The BICSS report recommended changes to ATC procedures designed to minimise language errors and compensate for the reduced effectiveness of the listening watch. These included encouraging pilots to use only one language in the course of a flight and the use of the ICAO phonetic alphabet to avoid confusion between English and French pronunciations of letters.

The Commission of Inquiry found that 83 countries used more than one language in air traffic control, as compared with 45 which used English alone. Some patterns were clearly apparent: countries using English alone were mainly those which are anglophone or which were colonised by Britain (e.g., the Bahamas, Barbados, Burma, Cyprus, Ghana, Pakistan). In the developed countries, all non-anglophone countries, except the Netherlands, used two or more languages for air traffic control. A study conducted for the Commission examined over 17,000 reports of accidents involving aircraft over 12,500 LB in weight from throughout the world and found only one which might have been avoided by the use of one language: a mid-air collision in 1960 involving a US aircraft being controlled in English and a Brazilian aircraft being controlled in Portuguese. The Commission drew the following conclusion:

> If one stops to think of the number of flights that must have been made, and of the miles flown, and the passengers carried, during the past 20 years in 83 countries throughout the world where air traffic control services are provided in two or more languages, one is left with an abiding conviction that there is nothing inherently dangerous in bilingual air traffic control. (quoted by Borins, 1983:186)

Subsequently, the use of French in domestic air traffic control was permitted in Quebec. An attempt to use French for international traffic flying into and out of the province was thwarted when pilots threatened to boycott the province.

4.4 Culture

Until the 1980's the term *culture* applied more to nationalities and was really only an interest to the aviation industry if it impacted on safety issues such as in Canada. Increasingly the term is now applied to organisation theory. A culture creates a homogenous set of assumptions and decision-making premises within the organisation such that, at work, "we are all, to some extent, culturally-bound in terms of our behaviours and attitudes" (Hayward, 1997). An organisation "is in a large part constituted by its speech exchanges" and "if that communication is misunderstood, the existence of the organisation itself becomes more tenuous" Weick (1990). Speech exchange and social interaction is an important means by which an organisation is built. The interest in organisational culture has led to the systematic investigation of organisational accidents. In aviation the emphasis is on developing a *safety culture*, the four critical subcomponents of which are a *reporting culture*, a *just culture*, a *flexible culture* and an *informed culture* (Reason, 1997).

Hayward's paper reviews the considerable amount of work which has examined the role of national culture in relation to flight crew behaviour. The unequivocal findings are that national culture is a powerful influence on work performance in the cockpit. The program of Cockpit Resource Management (CRM—now often called crew resource management), which sought to overcome problems of leadership, teamwork and personality interactions, has had to be tailored to fit with the national, organisational or vocational culture of the target population. National culture also affects how we attribute blame—what Reason (1997:127) calls *the blame cycle*. People of Western cultures place great value on their personal freedom. Because people are regarded as free agents, errors are seen as being, at least in part, voluntary actions. Thus we readily accept *human error* as a cause of accidents when it is really a consequence of other factors.

The national culture of a crew may impact on air traffic control communications in ways other than expected. The crew of Avianca 052 demonstrated a subordinate-to-superior relationship with controllers, unnecessarily accepting holding patterns and instructions despite their fuel emergency, and being indirect in their communications. There have been anecdotal reports of accidents occurring because pilots refused to abort landings for fear of loss of face. An American pilot may laugh at his attempts to report at "Boollooloo estimating Paraburdoo", but Korean or Japanese pilots may be too embarrassed to ask for track shortening if the new reporting points have words with "R's" in them which they find difficult to pronounce—the issue is loss of face, not accent.

Little work appears to have been published on culture in air traffic control. Owen (1995) studied the learning and organisational culture of ATC in Australia and noted evidence of a group culture including specialised language and symbols: "ATC has a highly stylised communication form. Inclusion in the group depends on being able to use this language competently, indeed effortlessly". That a workplace culture may work against safety was noted in the "Seaview Inquiry" (Staunton, 1996:272) which "found evidence of a local culture...this is Sydney, this is the way we do it...". It was related to a *laissez-faire* approach to procedures by flight service officers and air traffic controllers which was reflected in all the tape transcripts. In particular, few positions identified themselves, many non-procedural phrases were used and there was a "certain casualness in procedures which can certainly contribute to incidents and accidents". According to Reason (1997:121), violations of rules and procedures (as distinct from errors) have their origins in cultural factors, so it seems likely that these non-standard phraseologies were a manifestation of a poor safety culture.

Also noted by the Inquiry (p232) was a strong culture which sought to keep controllers and flight service officers "out of the cockpit" on the basis that the pilot is in the best position to fly the aircraft and make the complex decisions necessary to ensure its safety. But the Inquiry also found a pilot culture of reluctance to report difficulties, raising the question, if a pilot hasn't declared an emergency, at what point does a controller's unease trigger alarmbells? This was an area of some exploration by the Inquiry seeking to determine why flight service officers had not queried the pilot about his unplanned and, as we now know, significant level changes. Perhaps air traffic service officers have become overconfident and feel that they do not have to be alert for unannounced and undefined anomalies. Of the Avianca Flight 052 fuel starvation accident at New York, Besco (1997) contends that, although very busy, controllers had several opportunities to perceive and relieve a whole series of errors, oversights and misconceptions being made by each other. The pilot had asked for "priority handling". Yet because he had not used the word "emergency", or the distress calls "mayday" or "pan pan", the controllers responded to his low fuel situation, not his low fuel emergency.

CRM has aimed to improve co-ordination within the cockpit and cabin by altering attitudes of pilots from individuals to a more team-based approach. Proposals have been made to extend the concept to air traffic control but these have foundered because there is no history of controllers acting as "rugged individualists" (Bowers, Blickensderfer and Morgan, 1998), nor are the jobs as similar as outsiders might expect (Ruitenberg, 1995). Controllers working traffic are not subject to a similar hierarchial structure that exists in the cockpit. By its very nature, air traffic control requires continual communication and co-ordination between individuals to be effective.

4.5 Gender and Physiology

Gender has some bearing on communications in the air traffic system. In studies of individual differences in performance (Tattersall, 1998), females tend to perform better with respect to verbal-linguistic skills, whereas males perform better in visual-spatial and mathematical skills (the geometrical tasks rather than the computational). Males experience greater hearing loss with age than females, but vision in females declines at an earlier age. Females have superior pure-tone auditory thresholds, whereas males have better visual acuity. No gender differences were reported in the performance of various tasks in noise at different times of the day. My experience is that female voices are easier to hear on VHF (very high frequency) and especially the noisier HF (high frequency) channels.

Another aspect of gender is considered in HEART (Human Error Assessment and Reduction Technique), developed by Jeremy Williams, a British ergonomist (Reason, 1997). Error-producing conditions (EPC's) are ranked according to their relative influences and a means of assessing various violation-producing conditions (VPC's) has been determined. Unlike for errors, there is a large gender effect for non-compliance with rules and procedures. For males, a factor of 'x1.4' must be applied—that is, males are 1.4 times more likely than females to violate rules and procedures. We might, therefore, expect them to be more likely not to use standard phraseologies and approved key words.

It is well understood that illness can affect hearing and voice quality. It is also known that drugs impair performance. In 1975, during descent towards Nairobi, the co-pilot of a Being 747 misheard an air traffic controller's instruction; instead of "seven five zero zero" he heard, and readback, "five zero zero zero" and set the aircraft's flight management system to level out at 5000 feet. The incorrect readback was not detected due to other co-ordination occurring at the same time. When the aircraft broke through the cloud, the captain found himself a little more than 200 feet above the ground and 8 miles from the runway—the aircraft came within 70 feet of the ground before climbing away. It transpired that the co-pilot had been taking unauthorised drugs to remove a large tapeworm that he had picked up while holidaying in India (Accident Investigation Branch, 1975).

As regulations have become more complex, lawsuits more frequent, sums of money sought more exorbitant, and FAA enforcement policies more harsh, pilots have been less and less inclined to declare emergencies. Pilots and controllers have become increasingly concerned about possible legal implications instead of focusing on how to prevent serious accidents.

—Brenlove, M (1993:67)
Vectors to Spare: The Life of an Air Traffic Controller.

5. Air Traffic Control Communications and the Law

Airservices Australia was established as a Government Business Enterprise under the *Air Services Act 1995* with one of its six functions being the provision of air traffic services such as air traffic control and flight service. As noted earlier, the legal relationship between pilots and controllers under CAR 100 (4) is that "the pilot in command of an aircraft is responsible for compliance with air traffic control clearances and air traffic control instructions". Air traffic controller liability is determined in accordance with the principles of common law where negligence is conduct falling below the standard demanded for the protection of others against unreasonable harm. This standard is measured by what the reasonable person of ordinary prudence would do in the circumstances.

Negligence comprises three elements (Stewart, 1997):
- the existence of a duty of care owed to the plaintiff by the defendant;
- a breach of that duty, or a failure to conform to the standard of care; and
- damages to the person resulting from the breach, provided that there is some 'relation' or 'proximity' between the parties.

The plaintiff will fail in the action unless damage is proved (of a kind recognised by law) and it must be caused by the act or omission complained of. For example, we have the interesting finding in *The Public Trustee v The Commonwealth of Australia*, which arose out of the crash of a Beechcraft Super King Air at Sydney Airport in 1980, where the controller was found to be in breach of his duty, but since it made no difference to the ultimate outcome of the flight, there was no action or inaction on the part of the controller that contributed to the crash of the aircraft (Boughen, 1994).

The duty of care owed by controllers has been described as being "to take reasonable care to give all such instructions and advice as may be necessary to promote the safety of aircraft within their area of responsibility" (Shawcross and Beaumont, 1977, cited by Bartsch, 1996:192). This duty of care arises because the proximity or closeness of controllers and pilots is determined by the degree of reliance existing in the relationship: that is, are pilots reliant upon the acts, advice or information provided by controllers? "It is difficult to envisage any public authority in which the element of reliance is more prevalent than it is with the control of air traffic" writes Bartsch (p189). The apparent paradox that sometimes leads to confusion as to the respective responsibilities of pilots and controllers has been clarified by Hopkin (1995:28):

> The pilot is legally responsible for the safety of the aircraft and its passengers. The controller is legally responsible for the safety of the air traffic control instructions.

The issue of miscommunications, therefore, is at the heart of potential air traffic controller liability.

Airservices Australia is vicariously liable for any negligent act or omission on the part of a controller because legislation prohibits an employee being joined as a co-defendant or from being sued by a plaintiff. The relevant document outlining the duties and responsibilities of air traffic controller is the Manual of Air Traffic Services which contains instructions detailing communications and phraseologies to be employed.

Bartsch (1996) defines three main categories of potential liability. These are;

- a duty to provide information that is accurate and not misleading;
- a duty to warn of known dangers; and
- a duty to warn of potential dangers.

Listed in order of increasing uncertainty of outcome, it will be more difficult for a plaintiff to prove negligence in the latter situations. This due to the difficulty of not only showing the existence of a duty of care, but of proving that it was subsequently breached.

5.1 Duty to Provide Accurate Information

In 1975, the High Court of Australia considered the question of whether air traffic controllers owed a duty of care to pilots (and consequently their passengers) in *Australian National Airlines Commission v Commonwealth and Canadian Pacific Airways Ltd*. On the 29th of January 1971, a Canadian Pacific Douglas DC-8 had landed at Sydney's Kingsford-Smith Airport and the pilot had requested permission to backtrack along Runway 16. The air traffic controller gave the instruction "take taxiway right" which the pilot mistook for "you can backtrack if you like". In the resulting confusion a Trans Australian Airlines (TAA) Boeing 727 was cleared for take-off on the same runway—due to a hump in the runway the TAA crew were unable to see the DC-8. The fin and rudder of the DC-8 was torn off in the collision with the airborne B727's belly but there were no fatalities (Job, 1992).

The High Court found that both defendants, the controllers and the Canadian Pacific crew, were negligent with contributory negligence on the part of the TAA crew. Justice Mason referred to the failure of the air traffic controller to keep a proper look out and for issuing a clearance for immediate take-off without maintaining adequate visual and radio observations as being "a serious departure from the standards of a reasonable man" (Bartsch, 1996:194). The case clearly demonstrated that an air traffic controller may be held negligent if he or she provides misleading information upon which the pilot relies and which subsequently causes damage. It also showed that pilots are not relieved of responsibility to maintain situational awareness by gathering information from their own eyes, ears and instruments. The Canadian Pacific crew was found to be negligent in, amongst other things, not paying attention to the controller's instruction, in not querying or seeking confirmation of that instruction, and in failing to call the surface movements controller promptly after receiving the instruction to do so (Boughen, 1994).

The United States courts have followed a similar line of reasoning. In *Fair v United States* in 1956 the court made it clear that:

> when air traffic controllers provided information to pilots, whether or not required to do so under the circumstances, knowing that the information will be relied upon, the information must be accurate. If providing inaccurate information becomes a contributing cause of an accident, government liability will follow. (cited by Bartsch, 1996:195)

A similar conclusion was reached almost 20 years later in *Spaulding v United States.*

Perhaps most unsettling for controllers and pilots is that the notion of miscommunication between the Canadian Pacific crew and the tower controller, while a safety issue, was not an issue in determining legal liability. In a court of law, it is not necessary for the prosecution to prove anything at all about a controller's or pilot's state of mind at the time of the act—it is enough to establish that particular actions were carried out in certain circumstances. We can conclude that controllers must not only issue safe instructions but follow up and ensure that their instructions are being carried out.

5.2 Duty to Warn of Known Dangers

The duty of controllers to warn of known dangers has been classified by Bartsch (1996) according to the following situations:

- mid-air collision;
- wake turbulence; and
- weather related accidents.

The controller's duty to warn of potential mid-air collisions centres on the pilot's and the controller's knowledge of the facts of the traffic situation. In 1975, the Supreme Court of Western Australia determined the liability of air traffic controllers in *Nichols v Simmonds, Royal Aero Club of Western Australia and Commonwealth.* A Piper Comanche had collided with a Beech Musketeer when both aircraft were turning onto final approach to the same runway at Jandakot Airport. All parties were found guilty of negligence or contributory negligence.

This case established that controllers owe a duty of care to pilots and passengers even in situations where the pilots are generally responsible for their own separation. In the judgement of Justice Wallace:

> In my view, where there is a duty to submit and obey there is a corresponding duty to, inter alia, warn of danger within the limits of practicability in the performance of the controller's duty and having regard to circumstances prevailing in each particular case. (cited by Bartsch, 1996:198)

Another important issue arising from the *Nichols* case was that if a late warning is given by a controller, as it was here, this would not relieve the controller of liability. Warnings must be both timely and sufficient to alert the pilot of the extent and magnitude of the potential danger.

What is important to this paper on miscommunications is that the controller had used procedures specifically warned against in Airways Operations Instructions (the forerunner of the Manual of Air Traffic Services). Bartsch (p197) writes that "whenever damage results from persons deviating from set practices or established procedures then the onus is on them to show that such deviation was reasonable". Because of this deviation from documented procedures, Justice Burt stated that "In my opinion the negligence of [the air traffic controller] was more culpable than the negligence of either pilot". A controller using non-standard phraseologies and words must, therefore, be vulnerable to legal liability should an accident result from consequent miscommunication. A controller knowingly violating safe operating procedures is more culpable because he or she should be aware that it increases both the likelihood of inducing an error and the chances of bad consequences resulting from the error.

In 1974 two aircraft collided shortly after take-off at Bankstown Airport, killing two instructors and two trainee pilots. In *Skyways Pty Ltd and Navair Pty Ltd v Commonwealth*, the Supreme Court of New South Wales found the air traffic controller had been negligent because:

> ...there was a failure to act in accordance with the standards of a reasonable man in his position in all the circumstances and to comply with the relevant regulations, orders and instructions...(cited by Bartsch, 1996:199)

Australian courts have not had to consider topics of wake-turbulence and weather related accidents. Bartsch cites several cases from the USA where the court decisions have been consistent with *Nicholls* and *Skyways* in that it was held that controllers were under a duty beyond that prescribed in operational manuals. Of pertinent interest is *Hartz v United States* where improper phraseology was used in a warning given to the pilot of a Beechcraft Bonanza about a departing Douglas DC-7. The court found that the controller's warning of "prop-wash" (instead of "wake turbulence") was insufficient to adequately warn the pilot of the degree of hazard created by the DC-7. Furthermore, the controller had an additional duty, beyond that prescribed by the ATC manual, to delay the take-off clearance of the Bonanza for as long as reasonably necessary to permit the DC-7's turbulence to dissipate.

5.3 Duty to Warn of Potential Dangers

The two preceding categories show that when information is available to a controller, he or she might be liable if that information, when passed to a pilot, was either inaccurate, insufficient or untimely. What, then, of information that a controller should have known but had not obtained or pursued? There is no authority from the courts in Australia in situations not specifically addressed in terms of ATC operating procedures but there are several US precedents reviewed by Bartsch (1996). It seems likely that when attempting to establish whether a controller or pilot is liable, it will be important to determine which of the parties was in the best position to evaluate the situation. Should the information be available to the controller, liability may still be avoided if such information would have been available by some alternative means to a pilot exercising due care.

Mend your speech a little
Lest it may mar your fortunes.

—William Shakespeare
King Lear

6. Types of Miscommunication

The following list and short discussions of common forms of miscommunication is by no means comprehensive but it does give an indication of the scope of the problem. There is a great deal of overlapping, so the investigation of any incident is likely to provide examples at several levels, as with the much studied Tenerife accident. Miscommunication also involves such complex human attributes as complacency, fatigue, professionalism, personal problems, and so on.

6.1 Absent-mindedness and Slips

Absent-mindedness is a form of miscommunication which controllers and pilots will make occasionally. For instance, a controller may routinely assign the same level for descent to arriving aircraft. But on the one occasion that conflicting traffic at that level has been noted, the controller may still absent-mindedly assign that level to an inbound aircraft instead of providing level separation. Such slips are usually associated with some degree of attentional 'capture' such as an internal preoccupation or external distraction. The crucial point about absent-minded errors is that they are a characteristic of highly skilled or habitual activities (National Research Council, 1997; Reason, 1984). They are not signs of incompetence but of misapplied competence. They are a problem of experts, not of beginners. Thus the probability of making a absent-minded slip actually increases with task proficiency because, as we become more skilled at an activity, the less demands it makes upon our working memory. We perform at an automatic, subconscious level. Reason (1984) uses this example: should we inadvertently turn on the toaster instead of the coffee pot, the result is inconvenient. Should we make precisely the same mistake in the control room, the result may be catastrophic. The circumstances will determine the extent of the penalty. In such cases, the standard response of additional training "would appear to be counter-intuitive" (Shappell and Wiegman, 1997).

Spoonerisms and verbal blends are other forms of slips. Named after the Reverend W.A. Spooner (1844-1930), who said such things as "queer old Dean" when he meant "dear old Queen", they are most likely to occur when a controller is busy as, too, are verbal blends such as 'Tangee Yankee Delta' instead of 'Tango Yankee Delta'.

6.2 Ambiguity

As this paper has revealed, ambiguity can arise from many aspects of verbal communications. It has been implicated in many aviation accidents such as the 1992 Air Inter Flight 148 crash on Mont Sainte-Odile in France which killed 87 people where, because of the use of "less-than-optimum phraseology by both the flight crew and the controller, their respective intentions and expectations were ambiguous". This led to a sudden workload peak for the crew just prior to the crash (Pariès, 1996).

Workload may increase vagueness and imprecision. Vague vernacular, such as jargon and acronyms, may confuse pilots or controllers. Vagueness is also a social affectation, considered polite when addressing superiors, but it may also restrict the flow of information between ATC team members, reducing situational awareness (Morrow and Rodvold, 1998). Vagueness is often associated with trainee controllers and disappears with experience (pers. obs.).

Words with uncertain reference, such as the pronouns 'him' or 'it' or indefinite nouns such as 'things', may be ambiguous and can cause confusion, as we saw in the Florida Everglades crash in 1972.

A lack of definition can also be included here when controllers and pilots have differing understandings of words and procedures. Gero (1996) provides an example. In 1974 a Boeing 727 approaching Dulles Airport, Washington, was "cleared for a VOR/DME approach" which the pilot understood to mean he was cleared to the final approach altitude of 1800 feet and that there was no other terrain above that level on his route. The controller understood it to mean that the aircraft could descend without conflicting with other traffic and that the pilot was responsible for terrain avoidance. The aircraft crashed into a mountain. The subsequent inquiry found that there was confusion by both pilots and controllers regarding each other's responsibilities; everyone simply made their own interpretation. It found that pilots were often unsure of the type of radar service they were receiving. Twenty-five years later Airservices Australia is still encountering the problem:

> Pilots must be aware that the responsibility has shifted from the controller to them and is therefore incumbent on the controller to use standard phraseologies to ensure that pilots are in no doubt. (Airservices Australia, 1997a)

6.3 Callsign Confusion

Aircraft callsign confusion is a vexation throughout the world. It hampered ATC assistance to the charter DC-8 with an in-flight fire at Jeddah in 1991 which killed 261 people (Flight Safety Foundation, 1993), was implicated in the Boeing B737 and Metroliner collision in Los Angeles in 1991 (Maurino, Reason, Johnston and Lee, 1995*)*, and has caused numerous other incidents when pilots have accepted clearances meant for others. There have been calls in the UK and North America for a central system for controlling the allocation of callsigns (Job, 1997, Canadian Aviation Safety Board, 1990). One recent Confidential Aviation Incident Report (CAIR) complained that the following aircraft were on the same frequency: New Zealand 88, Qantas 28, Qantas 88, Qantas 188, All Nippon 828 and All Nippon 888 (BASI, 1998b). The writer complained of several mistakes on the radio. (Apparently the number '8' has significance in the Asian market—another example of how culture may impinge on aviation safety).

There has been a continuing trial of flight number callsigns in Australia. Job (1997) has argued against its acceptance due to the potential for confusion. Registration callsigns have 26 possible last letters whereas numbers have only 10. Also, he writes, crews become familiar with their registration callsign during a flight, but a flight number changes every leg. Following feedback from the industry, the flight number element of the callsign has recently been reduced from 4 digits to 2 for domestic flights. In my experience, registration callsigns play a significant role in situational awareness because pilots and controllers quickly learn to recognise aircraft-type/callsign associations (i.e. Foxtrot Kilo Golf is a Fokker F28, Romeo Mike Foxtrot is a B767).

6.4 Code Switching

Code switching refers to the habitual switching back and forth from one language to another of bilingual and multilingual speakers during the course of a conversation. This is due to inherent social and cognitive features of how language works that are still poorly understood. Perhaps the most well known example of this occurred at Tenerife (see appendix 2). The problem can also arise between speakers of the same language when different dialects are in use. Most importantly, it can arise when pilots or controllers switch between the common usage of a word and its more defined aviation equivalent. Cushing (1995) provides the communications transcript of the 1981 John Wayne Orange County Boeing 737 crash where the controller and pilots used the word 'hold' to mean 'stop' (its aviation meaning) and 'to continue' (as in 'hold your course' in ordinary English). Just what 'hold' meant in each transmission in which it was used led to confusion, a wheels up landing, 34 injuries, and an aircraft destroyed by post-impact fire.

6.5 Different Voices

ICAO (1993:16) reported that:

> Voices become familiar, and it can confuse the pilot if a different controller from the one expected replies, and confuse the controller if parts of a single dialogue with the crew of an aircraft are with different crew members.

A controller may be unsure that the correct aircraft has received the instructions, especially since pilots sometimes mix up their callsigns if they have flown several different aircraft recently.

6.6 Emergencies

Language skills diminish as tension rises during in-flight emergencies. Tasks take priority which means that controllers may have to concentrate in order to deliver slow, clear speech, especially those for whom English is not their first language. Distraction with an emergency may cause slips with communications with other aircraft (Porter, 1981).

6.7 Enunciation

Poor enunciation by a sender leads to doubt by the receiver as to what has been heard. Many controllers are not aware that they have inadequate enunciation and that it is the reason for unacknowledged instructions or requests for message repeats. Some people find certain words innately difficult to enunciate, particularly when they are busy, so, for example, 'Juliet Juliet Tango' becomes 'Jew Jew Tango' and a 'Bulls 2 arrival' becomes 'Buws 2 arrival'.

6.8 Expectation

We have discussed how we use expectation and context to hear and understand what has been said. Messages are misunderstood because the listener incorrectly infers the intended message. Expectation errors are a particularly insidious form of miscommunication because readbacks may indicate that the message has been received correctly when, in fact, it has not. Byron (1997) cites an example where an aircraft was cleared to climb to FL310 and at FL260 the controller asked about the aircraft's speed. The pilot answered "315 knots". The controller said "maintain 280", to which the pilot responded "280 knots". The pilot slowed the aircraft to 280 knots and continued climbing. As it climbed through FL295, the controller said that the aircraft was cleared only to FL280. In this case, the controller had set a context of airspeed and failed to indicate, due to his poor phraseologies (i.e. not saying "maintain <u>flight</u> <u>level</u> 280"), that the subject had changed to altitude, nor did he vigilantly monitor the readback and detect the pilot say "knots".

6.9 Headsets

Ill-fitting headsets cause many miscommunications problems because the microphones tend to drop away from the mouth. Microphone clipping occurs when a controller (or pilot) fails to ensure that the microphone switch is activated prior to speaking, or deselects it prior to finishing speaking. Since the aircraft's callsign is the first part of a control message, dropping the first letter from the callsign may mean, for example, 'Echo Alpha Kilo' accepts a message meant for 'Tango Alpha Kilo'. In order to detect this, recent changes require pilots to place their callsign last when acknowledging an instruction (i.e. "six thousand, Tango Alpha Kilo"). Problems with clipping of 'affirmative' and 'negative' led to the former being changed to 'affirm'.

Microphone clipping is most likely to occur when controllers and pilots are busy or training.

6.10 Homonyms and Homophony

The Flying Tigers Boeing B747 crash at Kuala Lumpur in 1989 demonstrates the misinterpretation which may occur with the homonyms ‘to, too and two’. Visibility was only two miles in fog as the aircraft was issued the clearance, “Descend to two seven zero zero” (two thousand seven hundred feet) to which the pilot responded, “Roger, cleared to two thousand seven hundred. We’re out of forty-five”. The next clearance was, “Descend two four zero zero” (two thousand four hundred feet) to which the pilot replied, “OK, four zero zero” (four hundred feet). The four crew, who did not heed the ground proximity warning alarm, were killed when the freighter crashed 8 miles from the runway (Waldock, 1994). Had the controller not dropped the ‘to’ in the second instruction and instructed “descend to two four zero zero”, or detected the incorrect readback, the accident would have been avoided. Controllers often encounter this problem with these homonyms and appear to use two different techniques to overcome it. One is to pronounce ‘to’ as ‘tah’; the other is to emphasise ‘to’ as in “descend **to** two seven zero zero”.

Homophony is a “confusion-inducing phenomena” due to different words or phrases sounding exactly or nearly alike (Cushing, 1994:12). Examples are ‘left’ and ‘west’, and aerodromes such as ‘Morawa’ and ‘Moora’, ‘Cowra’ and ‘Corowa”. We saw earlier that in the Canadian Pacific accident in Sydney, ‘take taxiway right’ was heard as ‘you can backtrack if you like’.

6.11 Noise

Noise causes message distortion and may be due to cockpit or ATC centre background noise, equipment noise, environmental noise (atmospheric static), substandard headsets or poor microphone technique.

6.12 Not Hearing

The problem of visual dominance phenomenon was discussed earlier. Not hearing important information is a clear sign that the controller involved is overtaxed (Ott, 1998). Such strain affects the hearing first before affecting the ability to think clearly and motor/manual dexterity.

6.13 Number Problems

Errors with numbers are ubiquitous, whether it be with callsigns, levels, heading, speeds, tracks, winds, latitudes and longitudes, and so on. It seems to occur most often when controllers give headings and distances in conjunction with altitudes (Grayson and Billings, 1981). Numbers are likely to be transposed and the error may not be picked up in the pilot readback. Indeed, the pilot may read it back correctly but enter the transposed sequence into the aircraft's flight management system.

6.14 Open microphones

Stuck microphones tend to occur in aircraft when handset switches unknowingly get jammed. This blankets out transmissions by other aircraft and the controller. The controller relies on other pilots recognising the situation and returning to their previous or another frequency for instructions. This situation is obviously dangerous if aircraft are in conflict with each other and require separation, but it also adds workload to adjacent controllers relaying instructions for the affected sector (Porter, 1981).

6.15 Readback Error

Readback of pertinent parts of a controller's instructions does not guarantee that the readback message has been accurately received. Too often, confirmation is given of an incorrect readback. The Aviation Safety Reporting System (USA) has labelled this phenomenon *hearback* and cited four major causes (Hawkins, 1993:167):

- similar aircraft callsigns resulting in confusion in transmission or reception;
- only one pilot on board working and monitoring the frequency;
- numerical errors, such as confusing 'one zero thousand' with 'one one thousand';
- expectancy—hearing what one expects to hear.

6.16 Similarity of SIDs, STARs and Waypoints

The similarity of names for standard instrument departures or arrivals may cause confusion and mistakes. Morrow (1997) cites two transitions 'Wave 1' and Wave 2' and two SIDs 'Dorval 5' and 'Dorval 6'—these are not unambiguous nor error-tolerant because they are too similar. A pilot may mistakenly fly the wrong one. Waypoint similarity can cause confusion. ROTAP and RONSA are similar distances from Perth to the north-east and -west respectively, as are POKIP and POMOT. A busy controller can mentally reverse the position of the two and develop a separation plan based on the incorrect route.

6.17 Speech Acts

Complexity is introduced into language resulting from the variety of functions—speech acts—that any sentence can represent, such as statement, question, request, and so on. As we discussed earlier, subtle differences in intonation and placement of pauses affects the way we interpret words. But when we are distracted, stressed or careless, these verbal 'keys' may be omitted or displaced, resulting in miscommunications. Hawkins (1993:169) provides an example of a near-miss at Stuttgart in 1977 when a query of "flight level 80 clear?" was interpreted as a statement "flight level 80 clear". In the resulting confusion, two aircraft passed within 400m of each other at the same level.

I have had the good fortune to hear a colleague prod a pilot for a readback of an assigned altitude by requesting, with voice intonation, "and level?", to which the pilot replied "affirm", meaning he was flying level!

6.18 Speed of Delivery and Pauses

During peak traffic periods, controllers in some positions may be talking constantly. Difficult as it may be, if controllers pause between transmissions to different aircraft, the amount of irrelevant information received by pilots is reduced. This increases the pilot's chance of remembering and reduces requests for reiteration.

Cushing (1994) refers to the danger of the 'delayed dangling phrase', an add-on during a transmission to a sentence that sounds, tonally and in contents, to have already terminated. Such afterthoughts risk being over transmitted and important information missed, as was the case in the Boeing 707 crash in the Azores in 1989 (Gero, 1996).

The rapid speed at which controllers deliver instructions is probably the most common miscommunication complaint received from pilots.

6.19 Vigilance

Maintaining vigilance for critical but infrequent events, such as a pilot reading back an incorrect level, is an important part of air traffic control. Traditionally, maintaining vigilance has been thought of as undemanding and boring but recent research shows that it imposes considerable mental effort and that this does not simply arise from the controller's efforts to overcome tedium (National Research Council, 1997). Issues of vigilance involve many types of human attributes such as boredom, stress, tiredness, personal problems and so on.

7. Conclusion

Errors in communications and co-ordination are causal factors in failures within the air traffic system. The flexibility of the system depends upon the highly dynamic information passed by voice between controllers and pilots. Without current, unambiguous information, neither pilots nor controllers can make appropriate decisions. Miscommunication, therefore, has obvious safety implications. The difficulty is not so much in routine situations but when situations become non-routine. Unfortunately, because of their differing perspectives of the system, the parties may not be aware that they have a miscommunication problem. This problem is greater for those whose English is poor but, as Morrow (1997:28) observes, “there is a hidden threat from those who take their fluency for granted”.

To a large extent, the norm for verbal communications in the Australian air traffic system has been established by the day-to-day example of air traffic controllers. Their small numbers, centrally controlled training and quality assurance structure, uniform culture and lack of regional accents have made it relatively straightforward to maintain high standards. This consistency has then been a model for the rest of the industry where there is greater variability in pilot training, experience and knowledge. At the time of researching this paper, however, the air traffic control structure is about to undergo fundamental changes. It seems likely that much of it will be privatised or disbanded. The large training commitment of the past decade is being wound down as Airservices Australia implements TAAATS (the Australian Advanced Air Traffic System). While enroute controller training is still conducted in-house, training for tower and approach controllers is being out-sourced. This fragmentation of the training effort can only make communications standardisation more problematic. The likely proliferation of unicom services, whereby certain aspects of airfield conditions and traffic information will be provided by local operators, is likely to introduce an element casualness and familiarity into radio communications which will gradually affect all air traffic services.

Recently, there have been calls for greater research into miscommunications and the means by which current research can be integrated with teaching and learning strategies (e.g. Henley, Wiggins and Anderson, 1997; Airservices Australia, 1997b). The first step is to begin applying what is already known. There is a need to heighten awareness amongst pilots and controllers of the nuances of language. As part of their training, they should be provided with a deeper insight into the structures of language and the way that phrases and words can be misinterpreted. They need to be mindful of how a transmission sounds to its recipient—a successful message must be sent, received and correctly interpreted—and be aware of, and avoid, common types of linguistic misunderstandings. Use of deliberate miscommunications should form a part of ATC training, and instructors and team leaders need to assiduously police ATC/pilot communications.

There has been a tendency over the past few years to understate or forget the role of verbal communications in the provision of air traffic services due, I believe, to the rapid advances in communications technology. The energy of air traffic controllers and Airservices Australia has been focused on implementing TAAATS, which brings with it the ability to exchange digital data between pilots and controllers using the global satellite system. This will be a major improvement for flights operating in oceanic airspace and some parts of continental Australia which still rely on HF voice communications. However, it will take many years for the world's aircraft fleet to be upgraded and many aircraft will never adopt the necessary technology. For the majority of controllers, working in high-density traffic areas, the immediacy and flexibility of VHF voice communications will ensure that it remains the primary means of communications with pilots.

8. Appendix 1 Case Study: Mount Isa, 1991

On March 1 1991, two Boeing 737 aircraft were operating opposite direction services between Darwin and Brisbane on a route which passes over Mt Isa, outside of radar coverage. Ansett's VH-CZG ('Charlie Zulu Golf') was operating from Darwin to Brisbane and Australian Airlines' VH-TJD ('Tango Juliet Delta') was operating Brisbane to Darwin. Once beyond radar coverage, pilots are required to give position reports and their cruising level at certain nominated points along the route. These reports, entered on a flight strip, furnish the data with which air traffic controllers establish aircraft separation based upon altitude, distance and time standards. The controller will pass an aircraft's position report to the next responsible sector prior to the aircraft crossing the sector boundary; this allows the receiving controller time to analyse the evolving traffic situation.

CZG departed Darwin and climbed to flight level (FL) 330. Prior to reaching Tindal the pilot requested, and was issued with, a clearance to climb to FL350. The subsequent position report at Tindal indicated that the aircraft was cruising at that level. The Darwin controller passed the Tindal position report to the Brisbane controller as "flight level three five zero". Brisbane Sector 5 was being operated by a trainee and training officer, and both heard the level as "three nine zero". The trainee read back "three niner zero". When the word 'niner' was received in Darwin, a temporary loss of clarity occurred. The Darwin controller heard 'five'.

Meanwhile, TJD had departed Brisbane and climbed to FL350. Passing Swords Range, the pilot reported maintaining FL350 and estimating Mt Isa at 0020 UTC (universal time). At Ubdog, CZG contacted Brisbane Sector 5 with its position report, maintaining "flight level three five zero" and estimating Mt Isa at 0024 UTC. The trainee, now with another training officer, did not detect the level discrepancy and left the flight strip endorsement as FL390.

With CZG's call at Ubdog, both aircraft were now on the same frequency and within radio range of each other. At 0020 UTC, TJD reported overhead Mt Isa, maintaining FL350 and estimating Ubdog at 0040 UTC. Shortly after this report the pilot of CZG asked for confirmation of the cruising level of TJD. The pilot of TJD confirmed that he was maintaining FL350, whereupon the pilot of CZG advised that he also was at that level and was turning left. The two aircraft were about 20 miles apart and would have been closing at 14 to 16 miles per minute. The training officer established the error with CZG's level and cleared the aircraft to descend to FL330. Each crew saw the other aircraft as they passed at 0021.

Miscommunication Issues

The BASI investigation found that all personnel involved were properly trained, licenced and medically fit. The trainee controller, while only in his first week of training, had eight years' experience as a flight service officer. There were other aspects to this incident which are not referred to here.

Equipment

The temporary loss of communications quality during co-ordination was determined by engineers to stem from two factors. Firstly, the trainee controller's microphone technique was such that, while the word 'niner' was spoken clearly enough for it to be recorded in Brisbane, it was not readable in Darwin. Secondly, audio levels were less than optimum in Darwin and had been for some time. These factors were enough to degrade the transmission of the word 'niner'.

Noise
Noise was a problem in the Brisbane Area Approach Control Centre. The room is small considering the number of people working there and the Sector 5 console is in close proximity to the flight data console. The controllers, however, reported that there were no distractions to their duties.

Phraseologies and pronunciation
The number nine was correctly spoken as 'niner' by all parties except the Brisbane trainee who often pronounced 'nine'. The one notable exception was when reading back the level of CZG after the Tindal co-ordination with the Darwin controller. On this occasion he said 'niner'—and it was not heard.

The Brisbane controllers misheard the flight level stated in two position reports (one by the Darwin controller and one by the pilot of CZG at Ubdog). All communications involving the number five were pronounced as 'five' by air crew and controllers alike. The number is required to be pronounced 'fife'. The word 'five' sounds like 'nine' whereas 'niner' has two syllables and is easy to distinguish from 'five' or 'fife'. The controllers were not in the habit of listening for a two-syllable word.

Readback error
The Darwin recording of the readback was monitored repeatedly during the investigation but nobody was able to identify the word recorded. The controller, however, was satisfied that she had received a valid response to her co-ordination. This may be an example of *expectation error*. The system has no protection against readback/hearback errors made by any one controller.

Sources: BASI, 1993; Byron, 1997; Airservices Australia, 1995.

9. Appendix 2 Case Study: Tenerife, 1977

Because a bomb had exploded at Las Palmas Airport in the Canary Islands, all flights had been diverted to Los Rodeos on the island of Tenerife. This airport had only one runway and inadequate parking areas to handle the sudden increase in traffic; the runway was 150 feet wide and a Boeing 747 requires 142 feet to turn 180 degrees. This meant that aircraft were parked on taxiways, obstructing others, and throwing into confusion the normal ATC ground handling procedures for taxiing, departing and arriving aircraft. Pan Am Flight PA1736 ('Clipper 1736'—a Boeing 747) landed just before Las Palmas reopened but, because it had to park behind KLM Flight KL4805 ('KLM4805', also a B747) which had off-loaded its passengers to refuel, it endured a delay of several hours, unable to move while the taxiway was obstructed.

Eventually, KLM4805 was cleared to taxi down the active runway to the end and make a 180 degree turn:

KLM: "We require backtrack on Runway 12 for takeoff on Runway 30."
ATC: "Taxi to the holding position for Runway 30...taxi into the runway...leave the runway third to your left."
KLM: "Roger, Sir. Entering the runway at this time...and we go off the runway again for the beginning of Runway 30."
ATC: "Correction...taxi straight ahead...ah...for the runway...make...ah...backtrack."
KLM: "Roger, make a backtrack...KLM4805 is now on the runway."
ATC: "Roger."
KLM (half a minute later): "You want us to turn left at Taxiway 1?"
ATC: "Negative, negative...taxi straight ahead...ah...up to the end of the runway...make backtrack."
KLM: "OK, Sir."

Pan Am was cleared to follow by entering the runway, taxi part the way down, then to vacate the runway onto a parallel taxiway; this would allow KLM4805 to take-off. Tenerife is 2073 feet above sea level and near the coast, which means clouds rather than fog float onto the airport. As KLM4805 backtracked, cloud moved in, obscuring the following B747 and blocking the controller's view of both aircraft. Pan Am was taxiing inside this cloud.

Pan Am: "Ah...we were instructed to contact you and also to taxi down the runway...is that correct?"
ATC: "Affirmative...taxi onto the runway third...third to your left."
Pan Am: "Third to the left...OK."
ATC: "Third one to the left."

The Spanish controllers English pronunciation was evidently unclear because the Captain remarked to the First Officer, "I think he said first", and the FO replied, "I'll ask him again". The controller, unused to handling B747's, had issued a taxiway exit requiring an impossible 148 degree left turn followed by another 148 degree right turn onto a 74 feet wide taxiway. Only taxiway 4 was suitable.
Pan Am: "Would you confirm that you want us to turn left at the *third* intersection?"

ATC: "The third one, Sir...one two three...third one."

Taxiing in cloud, the Pan Am crew had difficulty seeing the runway exits which caused some discussion. Meanwhile, the KLM Captain was completing the difficult manoeuvre of turning his aircraft about on the narrow runway. As his FO completed his pre-takeoff checks, the Captain opened the throttles slightly, which the FO checked with, "Wait a minute—we don't have an ATC clearance."

KLM Captain: "No...I know that. Go ahead and ask."
FO: "KLM4805 is now ready for takeoff...we're waiting for our ATC clearance."
ATC: "KLM4805...you are cleared to the Papa beacon...climb to and maintain Flight Level 90...right turn after takeoff...proceed with heading 040 until intercepting the 325 radial from Las Palmas VOR."
Captain: "Yes."

As the FO began to readback the clearance to the tower controller, the Captain released the brakes and advanced the throttles to takeoff power: "Let's go, check thrust".

KLM FO: "Roger sir, we are cleared to the Papa beacon, Flight Level 90 until intercepting the 325...we are now at takeoff."

The aircraft was already six seconds into its takeoff run.

ATC: "OK...standby for takeoff...I will call you."

Hearing this exchange the Pan Am crew were understandably alarmed.

Pan Am: "No, uh...we are still taxiing down the runway, the Clipper 1736!"
ATC: "Roger Papa Alpha 1736, report the runway clear."
Pan Am: "OK...we'll report when we're clear."
ATC: "Thankyou."

Fatefully, the Pan Am's transmissions conflicted with the controller's instructions to KLM. Instead of, "OK...standby for takeoff...I will call you", the KLM crew heard only, "OK" and a squeal of simultaneous transmissions. The rest of the transmissions between the tower and PanAm were audible on the KLM flightdeck, but by this time the aircraft was 20 seconds into its takeoff run upon which both pilots were fully concentrating. The Flight Engineer, however, was concerned:

KLM FE: "Did he not clear the runway then?"
KLM Captain: "What did you say?"
KLM FE: "Did he not clear the runway—that Pan American?"
Both pilots: "Oh, yes."

At this stage, Pan Am had missed the third taxiway intersect and was approaching taxiway 4. The crew felt uneasy on the runway in the poor visibility:
Pan Am Captain: "Let's get the hell right out of here."
FO: "Yeah...he's anxious, isn't he?"

FE: “After he’s held us up for all this time, now he’s in a rush.”

A few seconds later, the Pan Am crew sighted lights directly ahead through the fog.

Pan Am Captain: “There he is...look at him!...goddam...that son-of-a-bitch is coming!”

Desperately he pushed all four throttles wide open and attempted to swing the Boeing 747 off the runway to the left.

Pan Am FO: “Get off! Get off! Get off!”
KLM Captain: “Oh...”

Sighting the Pan Am jet slewing across the runway, the KLM Captain hauled back on the control column to try to lift over the other jet, dragging the tail bumper on the runway. The main undercarriage and No. 4 engine sliced off Pan Am’s fuselage top and the hump just behind the flightdeck. Both aircraft burst into flames. The KLM aircraft remained airborne for a few seconds before crashing back onto the runway: all passengers and crew were killed. Sixty-one passengers and crew of the Pan Am 747 survived.

Miscommunications Issues

English as a second language
The tower controller had a thick accent and pronunciation difficulties with English. He had difficulty formulating his instructions due to the non-standard nature of the operations caused by congestion.

Once, and only once, he called the Pan Am jet by its phonetic callsign “Papa Alpha 1736”; this occurred at a critical point when the KLM crew were concentrating on their takeoff. Perhaps if he had said “Clipper 1736” it might have caught their attention.

Also noted was a tendency for the controller to begin transmissions with “OK”; thus when Pan Am blocked the rest of the transmission of “standby for takeoff”, the word “OK” seemed a satisfactory response to the KLM pilots’ actions and served to confirm that all was well.

The KLM pilot’s statement of “we are now at takeoff” is a case of *code switching.* In Dutch, the verb ‘flying’ is expressed as ‘at fly’, so that “we are flying” translates as “we are at fly”. The KLM pilot meant that he was taking off; the tower controller, who had not issued a takeoff clearance, interpreted the sentence as, “we are now in the takeoff position”. The controller also used Spanish language constructions in some of his transmissions.

Expectation error

The KLM pilots were keen to depart. The pilots and the controllers *ambiguously* used the words ‘takeoff’ and ‘clearance’ in the same sentences—the pilot for the clearance request and the controller for the enroute clearance. The controller meant the instruction to be the route clearance after a takeoff clearance which was yet to come—this is standard procedure. The pilots, having completed their checks and lined up ready to depart, had wanted both clearances and that is how the KLM captain understood “you are cleared”. (It is unusual for the route clearance to be given when the aircraft is lined up. The controller had offered it earlier but the crew were too busy to accept it.)

The KLM captain had been a simulator instructor for more than ten years. In simulation, in order to get a flight underway and not waste training time, takeoff and route clearances are often issued together by the instructor; practice takeoffs often occur without any clearance whatsoever. Under pressure, the captain appears to have reverted to what he had done most often when sitting at the head of a runway. *Regression* occurs when a person reverts to first learned responses.

Simultaneous transmission
Over-transmitting blocked important instructions. With none of the parties in visual contact, the controller and the two aircraft were totally dependent upon radio communications for their situational awareness.

Standard phraseology
Neither the controller nor pilots used standard phraseologies in their communications and this contributed to misunderstandings. They were, however, those in normal daily use in civil aviation at the time.

Sources: Cushing, 1994; Gero, 1996; Hawkins, 1993; Job, 1994; Stewart, 1986; Weick, 1990.

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