WORDS THAT CAN BE HAZARDOUS TO YOUR HEALTH

Original idea from Steve Cushing

Miscommunication arising from spoken interaction is a fact of life experienced, in one form or another, almost daily. Even two people speaking face-to-face, ostensibly in the same language, with a common background in the subject of the communication, frequently discover that what was meant was not what was understood. In casual discussion or routine business situations, the results of such miscommunication can range from amusement to expensive errors. But in aviation, the outcome of spoken miscommunication can be deadly. In no area is this more true than in pilot-Air Traffic Control (ATC) interaction.

Various researchers have categorized the types of errors in reports of pilot-ATC misunderstandings. Some errors were caused by technical problems such as poor microphone technique or frequency congestion. Others resulted from mis-steps that were not specifically linguistic, such as failure to provide necessary information, or failure to monitor transmissions. These types of errors could be prevented or ameliorated through better conditions, training or discipline. More serious, because more difficult to solve, are problems that arise from characteristics of language itself and from the ways that the mind processes what is heard. Grayson and Billings' taxonomy of pilot-ATC oral communication problems included ten categories, of which at least three were specifically linguistic : "ambiguous phraseology", "inaccurate (transposition)" and "misinterpretable (phonetic similarity)". Monan identified "failure modes" that included misheard ATC clearances, cockpit mismanagement resulting in read-back errors, inadequate acknowledgements, apparent inattention to amendments to ATC clearances/ instructions, [controller] failure to hear errors in pilot read-back and clearance amendments not acknowledged by pilots and not challenged by controllers.

Pilot-ATC communication phraseology errors are divided into nine types. They included grouping of numerical information contrary to U.S. federal air traffic control regulations; failure to group numbers as specified in regulations; transposition or using numbers or words in the wrong order; and "dysfluency", including unwarranted pauses.

More than 200 communication-related aviation incidents, some of which resulted in disastrous accidents and the rest of which easily could have, have been analyzed by the author. The incidents were taken from U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) reports, U.S. National Transportation

Safety Board (NTSB) accident reports and from audio recordings of ATC exchanges with pilots. Many of these incidents were linguistic-based, perhaps exacerbated by nonlinguistic factors such as distractions, fatigue, impatience, obstinacy, frivolousness or conflict.

Language is replete with ambiguity, the presence in a word or phrase of more than one possible meaning or interpretation. In a study of 6527 reports submitted by pilots and controllers to ASRS, there were 529 reported incidents that the authors, Grayson and Billings, classified as representing "ambiguous phraseology".

On 27 March 1977, the pilot of a KLM Boeing 747 radioed, "*We are now at take-off*", as his aircraft began rolling down the runway in Tenerife, the Canary Islands. The air traffic controller mistook his statement to mean that the aircraft was at the takeoff point, waiting for further instructions, and so did not warn the pilot that another aircraft, a Pan American Airways B747 that was invisible in the thick fog, was already on the runway. The resulting crash killed 583 people in what is still the most destructive accident in aviation history.

The KLM pilot's otherwise perplexing use of the nonstandard phrase "at take-off", rather than a clearer phrase such as "taking-off", can be explained as a subtle form of what linguists refer to as "code switching". Careful studies of bilingual and multilingual speakers have shown that they habitually switch back and forth from one of their languages to another in the course of a conversation, not because of laziness or lack of attention, but because of inherent social and cognitive features of how language works, that are still poorly understood.

In the KLM pilot's case, the form of a verb that is expressed in English by the suffix "-ing" happens to be expressed in Dutch by the equivalent of "at" plus the infinitive (the uninflected form of the verb, e.g., "fly" as contrasted with "flies", "flying" or "flew"). For whatever reason, perhaps because of fatigue or the stress of having to work in conditions of low visibility, the normally Dutch-speaking pilot inadvertently switched into the Dutch grammatical construction while keeping the English words. The Spanish-speaking controller, proficient in English but not in Dutch, and unattuned to subtle linguistic phenomena, had no clue that this shift was going on. He interpreted the "at" in a literal way, indicating a place, the take-off point.

The controller at Tenerife had, a few seconds earlier, inserted another kind of ambiguity into the control tower-KLM pilot exchange. The controller had said, "KLM eight seven zero five you are cleared to the Papa beacon, climb to and maintain flight level nine zero, right turn after take-off ..." The tower intended the instruction only to mean that the KLM aircraft was vectored to the Papa beacon following a takeoff clearance that was still to come, rather than that the pilot was given permission to take-off. But that was not how the KLM pilot understood "you are cleared".

Code switching can take place even when speakers have the same native language, when different dialects or variants are available. One example occurred in the accident at John Wayne/Orange County Airport in Santa Ana, California, on 17 February 1981.
Air California Flight 336, a Boeing 737, was cleared to land at the same time as Air California Flight 931 (another B737) was cleared to taxi into position for take-off, but the controller decided that more time was needed between the two scheduled events and so told the Flight 336 captain to go-around.

Flight 336's captain chose to have his first officer radio for permission to continue landing, but the pilot used the word "hold" to express the requested continuation, inadvertently switching from technical aviation argon to ordinary English vernacular while speaking to the first officer. The first officer then radioed : "Can we land, tower?"

In aviation parlance, "hold" always means to stop what you are now doing. But in ordinary English, "hold" can also mean to continue what you are now doing (as in "hold your course"). The controller's seemingly self-contradictory instruction to Flight 931 to go ahead and hold at almost exactly the same time further exacerbated the situation, especially in view of the similarity of the two aircraft's identifying call signs and the consequent uncertainty as to just who was being addressed with that instruction. The resulting confusion led to 34 injuries, four of them classified as serious. The Flight 336 aircraft was destroyed by impact and post-impact fire when it landed with its gear retracted, the pilot having finally decided to follow instructions to go-around, but too late to actually do so.

Problems can also arise from homophony, the occurrence of different words that sound almost alike, such as left and west, or exactly alike, such as *to and two.* The latter misunderstanding actually led to a fatal accident at a southeast Asian airport.

ATC cleared the aircraft to descent "two four zero zero". The pilot read back the clearance as, "OK. Four zero zero". The aircraft then descended to 400 feet rather than what the controller had meant, which was 2400 feet. In another case a captain, who was the pilot flying, heard his co-pilot say, "Cleared to seven". He began a descent to 7000 feet (2135 meters), but at 9500 feet (2898 meters) the co-pilot advised the captain that 10,000 feet (3050 meters) was the correct altitude. The co-pilot's communication, which the captain had heard as *cleared to seven,* was in fact *cleared two-seven -* meaning the assigned runway for landing was 27L.

In written language, tiny differences in punctuation can drastically change the meaning of a sentence. (Compare these: "The flight attendant called the passengers" names as they boarded 'vs'The flight attendant called the passengers names as they boarded'. That little apostrophe after passengers represents the difference between an action likely to evoke a smile from the passengers and one likely to result in shock and outrage.)

Similarly, in spoken language, subtle differences in intonation and placement of pauses provide clues about how the words are to be interpreted. A simple, one-word exclamation – right ! - can be understood as enthusiasm, resignation or sarcasm, depending on the intonation. But when a speaker is distracted, stressed or careless, these verbal keys can be omitted or displaced, resulting in an important component of the communication being lost.

A flight instructor giving a check ride noticed that the pilot of the small aircraft added power just before touching down, contrary to the instructor's order. The instructor thought he had said, "Back ... (pause) on the power". What the pilot heard was, "Back on ... (pause) ... the power".

Excessive pauses within a transmission can lead to what Monan called the delayed dangling phrase, which he defined as the add-on of an explanatory phrase or sentence to a transmission that sounds, tonally and in contents, to have been already terminated. On a congested frequency, he noted, such afterthoughts run the risk of covering, or being covered by, another transmission. Monan reported this example from the ASRS data base:

An air carrier pilot radioed: "[Call sign] is maintaining zero nine zero ... (pause) ... as assigned". The pilot then heard the approach controller transmit: "... turn to one eight zero degrees". The pilot responded, "Roger, [call sign], turning to one eight zero". Thirty seconds later, the approach controller radioed:"(Call sign) where are you going ! You were given zero nine zero. Turn immediately and climb ..." It was some time before the pilot comprehended what had happened. The 180-degree heading had been for another aircraft: "as assigned" had blocked the other aircraft's call sign.

Further complexity results from the variety of functions - what linguists call speech acts - that any sentence can represent, including statement, question, request, promise and so forth. In spoken English, the structure or grammar of a phrase (especially if given in an abbreviated, shorthand form) does not necessarily indicate its function, and this can wreak havoc in even the simplest of situations. For example, a pilot misconstrued the phrase *tra ffic* ... *level at 6000* [feet] to be an instruction for himself, meaning [descend to and remain] level at 6000 [because of traffic], rather than an assertion about his traffic, meaning [the traffic] is level at 6000 as the controller intended.

Words with uncertain reference, such as the pronouns *him or it,* or indefinite nouns such a *things,* can cause considerable confusion in aviation communications. For example, in an accident that occurred at the Florida Everglades on 29 December 1972, the pilot and crew of an L-1011 had been pre-occupied with a nose-gear problem that they had informed several controllers about during their trip. When the Miami International Airport approach controller noticed on radar that their altitude was decreasing, he radioed, "How are things coming along up there ?" and the flight crew responded "OK". The crew was referring to the nose-gear problem, which, as it happens, they had just managed to fix, entirely unaware that there was any problem with altitude. But the controller interpreted OK as referring to the altitude problem, because that is what he had had in mind when he radioed the question. The crash killed 101 people.

To clarify the time frame of an instruction, and thus to avoid the kind of confusion that apparently occurred in the Tenerife accident when an instruction about what to do after take-off *for which permission had not yet been given,* seemed to imply take-off clearance, controllers use the words anticipate or expect. Such modifiers are helpful, but they are not without dangers of their own.

The expectation of an instruction can prime a pilot to mistake a different communication for the anticipated instruction. In their study of more than 6000 ASRS reports, Grayson observed that "many instances of misunderstanding can be attributed to the expectation factor, that is, the recipient (or listener) perceives that he heard what he expected to hear in the message transmitted. Pilots and controllers alike tend to hear what they expect to hear. Deviations from routine are not noted and the read-back is heard as being the same as the transmitted message, whether correctly or incorrectly".

This was demonstrated as recently as May 1995 at Heathrow Airport, London, when a Lufthansa Airbus A300 took off without ATC clearance. (It was the sixth such incident at a major UK airport since 1990.) Investigators said that having lined up, the crew expected that their next instruction would be to take-off. In a fast-moving queue for take-off, the crew were further primed when they had lined up by seeing the aircraft ahead of them take off.

In another incident, an aircraft cruising at FL310 asked for a descent clearance to FL240 and was told to expect the clearance in 20 miles. After a flight attendant came to the cockpit to discuss a recurring temperature problem, the captain mistook the first officer's read-back of a clearance to 280° heading as a clearance to FL280 and began a premature descent. The similarity of FL240 and FL280, and the force of expectation, combined to give a false impression.

Failure to make a clear distinction between a conditional statement and an instruction can put one or more aircraft in peril.

During cruise at FL230, a co-pilot, who was the pilot flying, asked ATC for permission to climb to FL310. The controller replied, " FL310 is the wrong altitude for your direction of flight I can give you FL290..." The co-pilot replied, "Roger, cleared to FL290, leaving FL230". The controller did not challenge the read-back. When the aircraft reached 24,000 feet, the controller queried the aircraft's altitude and said, "I did not clear you to climb,

THE AIM OF "ROGER"

According to the Pilot/Controller glossary of the Airman's Information Manual (AIM), "roger" means "I have received all of your last transmission", it should not be used by pilots or controllers to answer a question that requires a "yes" or "no" response. (Editor's Note: The meaning of "roger" is exactly the same in the UK. [CAA CAP 413, page 18, January 1996]). In this incident, reported to ASRS, the pilot of a small aircraft questioned a controller's use of "roger":

We were cleared by the tower to depart and climb north-east-bound. We noticed an aircraft approximately 50 feet below us and climbing. I told the tower we had traffic off our wing. The tower acknowledged by saying "roger".

"The aircraft began turning northbound toward us, at which point we took evasive action to avoid a mid-air-collision."

The aircraft continued climbing and continued north-bound. I questioned the tower again about the traffic, and again, the tower only answered ..roger".

Upon landing I telephoned the tower to try and clear up several questions about the tower's responsibility. The controller's response was that once we had the traffic in sight it was our responsibility to maintain visual separation. And that he was not in contact with the plane in question. The way the controller stated "roger" on our initial call gave me the impression that the tower was aware of the traffic and it was under his control.

it appears the pilot of the other aircraft was flying in Class D airspace without contacting the tower. The report does not say whether the tower was radar equipped. This does make a different, since the conflict was estimated to have occurred two miles from the airport at 2300 feet MSL. If the tower lacked radar, the controller's "roger" may have been appropriate. However, an optional message from ATC - "I'm not in contact with the traffic" would have been helpful to the pilot.

If the tower did have radar, the controller might have announced, "You have traffic at (o'clock position)". However, the AIM notes that the issuance of a safety alert is contingent upon the controller's capability to have an awareness of the situation. Controller workload, poor radar return of transponder signals, and the lack of aircraft transponders, can all reduce the controller's ability to have this awareness. In this incident, the controller apparently had no knowledge of a second aircraft until the call-out from the reporter.

Finally, the AIM and the FARs both state that the job of safely flying the aircraft remains with the pilot. As the controller observed, it was the pilot's responsibility to practice the see-and-avoid concept and maintain separation.

descend immediately to FL230. You have traffic at eleven o'clock, 15 or 20 miles". The pilot had understood "I can give you FL290" to mean "You are cleared to climb to FL290".

Misunderstanding can derive from the overlapping number ranges that are shared by multiple aviation parameters. For example, 240 can be a flight level, a heading, an air speed or the airline's flight number.

Aircraft call signs are particularly apt to be confused with one another.
Incidents in which one aircraft accepted an instruction meant for another have included pairs with only mild similarities; for instance, "TWA 232" vs "United 692" and "Air Cal 127" vs "Air Cal 337".
An aircraft was flying on a heading of 300 degrees at FL270 when ATC vectored the aircraft to "three one zero". The aircraft's first officer acknowledged "three one zero" and then climbed to FL310 instead of turning to a course of 310 degrees.

Another aircraft was in fact cleared to FL310. At about FL260, the controller asked about the aircraft's airspeed. The pilot answered, "315 knots". The controller said, "Maintain 280". The pilot answered "280 knots", slowed to 280 knots, and continued the climb to FL310. At about FL295, the controller asked for the aircraft's altitude and the pilot replied, "295". The controller said that the aircraft was cleared only to FL280.

In this case, the controller had established a context of airspeed through his first question and failed to indicate that the subject had changed for his next question. The pilot had then given a read-back that combined what the controller actually said ("280") with the presumed context ("knots"), and the controller had not taken notice of the extra word.

Researchers have suggested that the possibility of confusion about the sequence or meaning of numbers is enhanced when two or more sets of numbers are given in the same transmission. Especially in a high-pressure, high-workload cockpit or tower, it would require no more than a momentary slip of attention to transpose a three-digit flight level and a three-digit heading.

Grayson and Billings wrote that number-sequence errors "seem to occur most often when ATC gives assigned headings or distances in conjunction with changes in assigned altitudes in the same clearance".

Monan, in his study of ASRS incident reports, said that "one error pattern could be clearly identified : mishearing of the numbers occurred most frequently when single, one sentence clearance messages called for two or more separate pilot actions. Thus, "cross XYZ at one one thousand, descend and maintain one zero thousand, reduce speed to 250 knots.......

Salzinger noted that "it is well known that saying a number after another number that is supposed to be remembered creates the classic condition for confusing the numbers. Yet this is precisely what happens when the pilot states an understood numeric command (such as an assigned altitude) and then states the flight identification, which is itself a number".

To make the problem even worse, extensive repetition of instructions in essentially the same format, such as "cleared to -- feet"; "expedite", can have an extremely dulling effect on a pilot's consciousness. Such an effect, especially during a heavy workload phase of flight can encourage language based mistakes.

The primary responsibility for clear, comprehensible radio-communication is on pilots and controllers.

Pilot-ATC communications technique has evolved into a four-step system that involves a "confirmation/correction loop". The steps are: (1) Sender transmits message (2) Recipient actively listens to message (3) Recipient repeats the message back to sender and (4) Sender actively listens for a correct read-back. The system's built-in safety margin depends on all four elements of a communication being performed correctly.

Linguistic errors generally represent an aberration in step (1): the transmission falls victim to one of the kinds of anomalies discussed in this article. Awareness of linguistic traps may help to avoid introducing them into the communication in the first place, but under workload pressure it will be the rare person who can completely avoid them. Therefore, strict adherence to steps (2) through (4) becomes the next line of defence against errors.

In his 1988 ASRS report study, Monan wrote that 'perhaps the most important ... pattern emerging among the findings of this study was a strong indication that an essential redundancy - the fail operational, double-check procedure elements recently termed "hear-back" frequently is missed from controller-pilot-controller dialogues'. Among the ways that the absence of a confirmation monitoring step manifests, Monan said, are:

- A controller does not hear - or does not listen to - a pilot's incorrect read back. The pilot accepts the lack of response as silent confirmation that the read back was correct.
- After receiving an instruction, the pilot signs off with an inadequate "roger", or "okay", or "so long", which precludes any controller double-check of the exchange.

The ASRS reports in Monan's 1988 study contained a number of complaints by pilots, of controllers' failure to correct mistaken readbacks. Among the comments he quoted were these : "My impression is that controllers are not in a listening mode.
As soon as they issue a clearance, they start talking to other aircraft and pay no attention to the read backs."
"It is my opinion that I could read back my Social Security number and most controllers would not question it !"

Monan pointed out, however that the airmen tended to downgrade the significance of their own listening errors as less critical than the monitoring role of the controller. Moreover, he suggested that flight crews relied too much on controllers' active listening. Half-heard, doubtful, sometimes guessed-at numbers for headings, altitudes, taxi hold points, or Victor airway routings - if their read backs passed unchallenged were accepted by the airmen as validated, double-checked instructions as to where to fly their aircraft. Clearances were accepted for descent to low altitudes while well outside normal distance-to destination range, climbs above usual altitudes, turns 180-degrees away from desired track, wrong direction flight levels, descents in cloud down through tiers of aircraft in a holding stack and IMC descents below known mountainous terrain. The airmen subordinated common sense judgment and operational practicality to an assumption from a controller's silent' confirmation' of their read backs.

Morrison and Wright, in their review of ASRS records from January 1986 to September 1988, found that "too rapid issuance of instructions" (speed feed) was the most common delivery technique problem cited. In a 1983 study, Monan discussed the related problem of "non-stop ATC transmissions".

He wrote, "run-on ATC messages - instructions to one aircraft continuing without a break in transmission into multiple instructions to numerous other aircraft - evoked a series of pilot protest reports to the ASR 'The controller issued instructions to 12 different aircraft, all in one, non-stop transmission ... the controller was so busy that he had to talk continuously for up to 45 seconds at a time...'"

Although recognizing the realities of congested traffic conditions approaching major terminals during peak periods, and often complementing controller for doing a good job under difficult circumstances pilots nevertheless pointed out a double danger from "non-stop transmissions". First, it makes it easier to miss one's own aircraft's call sign in the jumbled messages, and second, there is no opportunity for read back acknowledgement and the controller will not know of any missed instructions.

Pilot-ATC communications difficulties have been extensively studied: in their survey of the research literature, Prinzo and Britten reviewed 43 reports. But the problem will not be easy to eliminate. In the 1988-1989 period, ASRS reports citing faulty readback or hear-back technique increased by two percent. As the Airbus A300 incident at Heathrow (cited earlier) suggests, pilot-ATC communications problems still occur, even at major airports with highly experienced controllers and pilots.

Nevertheless, research does suggest some way that pilot-ATC linguistic problems can be alleviated.

Prinzo and Britten, in their survey of research in the field, wrote that taken as a whole, the studies presented here indicated that :

- Only a few speech acts should make up a single transmission.
- The speech acts making up a transmitted message should be topically related.

Citing a particular group of studies, Prinzo added that this research suggests that :

- Pauses between messages should be of sufficient duration so the message can be completely understood before more information is transmitted.
- Some research suggests that the technique of "chunking" orally transmitted information into smaller units makes it easier to comprehend. For instance, a four-digit transponder code *(two seven seven two)* may be easier to understand and retain if presented as two, two-digit numbers, *(twenty-seven, seventy-two).*
- Flight crews should not assume that a routine read-back of a questionable clearance or instruction is adequate for confirmation. They should call attention to their uncertainty by prefacing their read-back with the word, "Verify".

Another approach would involve intensive efforts to develop a heightened awareness in pilots and controllers of the nuances of language and of the dependence of both their own and other people's safety on their willingness to use language more mindfully. For example, NASA's ASRS program, based at Ames Research Center in Mountain View, California, issues alerts on threats to aviation safety that it finds to be particularly prevalent, many of which involve issues of language and communication.

The Centre de Linguistique Appliquee of the Universite de Franche-Comte in Besançon, France, develops sophisticated training material for pilots and controllers and sponsors a triennial international Aviation English forum.
Much more needs to be done in this area, especially in the United States, where English is taken for granted as a language that everyone is expected to speak correctly in a standard way, in contrast to Europe or Asia, where the co-existence of multiple languages forces people to take linguistic issues more seriously.
As the Tenerife and John Wayne accidents reveal, a clearer understanding of linguistic processes and mechanisms such as code switching would help speakers in pilot-ATC communications avoid potentially problematic formulations.

Another path is the development of technological communication tools. Although such tools would probably be of limited use in emergency situations which require split-second decisions by human beings, technology can reduce the number of emergency situations that arise.

A close-to-ideal solution to at least some of the sorts of problems discussed in this article would be the development of an intelligent voice interface for aviation communication.

Such a device would monitor communications and filter out potential linguistic confusions, if necessary checking with the speaker for clarification before conveying messages, and monitoring the aircraft's state, providing needed call-outs automatically. The system would be valuable on line, as a safety device in real time, but would also be useful as a training device, an aid to developing an awareness in both pilots and controllers of the kinds of linguistic constructions they ought to avoid.

It might also be helpful in furthering our understanding of phenomena such as code-switching as basic linguistic research reveals more clearly the mechanisms and triggering factors that bring such phenomena about. Developing such a system would require extensive further research to solve many still open questions of scientific linguistics such as the problem of speech recognition. That is, how to extract a meaningful message from an acoustic wave. This problem has become tractable technologically for individual words but still resists solution for more extended conversational utterances.

There are also many unsolved problems of what linguists call pragmatics, that is, ways in which context can effect the meaning of an utterance. For example, the sentence *"I have some free time"* means one thing when uttered during a discussion of one's work schedule, but means something quite different when uttered after just having driven one's car up to a parking meter. People routinely distinguish such meanings in real conversations with very little effort, but exactly how they do that, and how what they do can be implemented in workable tools, will only be discovered as basic research in linguistics progresses. The only certainty is that a workable intelligent voice interface is a very long-term goal, not likely to be developed for this, or the next, generation of aviation.

In the meantime, and in parallel with that research, it may be more fruitful to develop more limited systems in which a visual interface for processing a more restricted English-like language is used.

One system that offers hope of overcoming problems in radio-frequency voice communications for ATC is the Aeronautical Data Link system (ADLS), now being developed by the FAA in co-ordination with the International Civil Aviation Organisation (ICAO).

ADLS enables digital transmission of messages between pilots and controllers through a two-way data link (TWDL). Coded messages, modeled after existing ATC phraseology, will be transmitted by this alternative to radio, and the digital data can be decoded at the receiving end as text, graphics or speech. With a TWDL system, more information can be exchanged in less time and with less demand on voice channels.

A prototype version of another such system, the Aviation Interface Research (AIR) system was developed by graduate students under the author's supervision at Boston (Massachusetts) University. AIR uses a system of nested menus (in which choosing a menu item brings up another menu) to send messages back and forth between two Macintosh computers, which simulate pilot and controller interfaces.

When a message is entered from one of these two user interfaces, a program called a parser checks that it is correctly formed with respect to the restricted English-like language that is used by the system, before permitting it to be transmitted to the other interface, where it appears at the top of the screen. If necessary, an error message is returned to the sender instead. Menu screens are invoked by selecting symbolic icons and messages are constructed by selecting buttons that contain actual words or phrases which are echoed at the bottom of the sending screen. On the prototype system, selections are made by mouse but they could well be made, more conveniently in a pilot-ATC communication situation, by touch-screen.

As it now stands, AIR serves mainly to illustrate the concept and demonstrate the feasibility of an error resistant visual message-sending and - receiving system for pilot-controller communication. A second version is envisioned as having further features that will improve on the current system in several ways.

For example, it will be possible to provide bilingual screens, in English and in the user's own language, to enable the crew or controller to check the correctness of messages they receive. It will also be possible to have the system choose randomly from a set of synonymous alternative formulations of an instruction in order to pre-empt the semi-hypnotic boredom that is induced by repeatedly receiving instructions of exactly the same form. Further research and development of intelligent error-resistant voice and visual systems such as AIR can reasonably be expected to offer substantive progress toward technological mediation in communication for the aviation setting.

In the meantime explicit instructions by controllers, complete read-backs by pilots, and active listening by controllers to pilots' read-backs are the best defense against miscommunication ... which, at worst, can mean fatal words.