2007

# Linguistic Factors in the Overall Aviation Safety Framework

S. Bourgeois-Bougrine

V. Normier

R. Mollard

O. Ferrante

Y. Pouliquen

# LINGUISTIC FACTORS IN THE OVERALL AVIATION SAFETY FRAMEWORK

Bourgeois-Bougrine, S. ; Normier, V. ; Mollard, R.
Laboratoire d'Anthropologie Appliquée (LAA) - Ergonomie - Comportement et Interactions (EA 4070)
Université Paris Descartes, France

Ferrante, O. ; Pouliquen, Y.
Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), Le Bourget, France

Feedback on occurrences and some safety studies prompted ICAO to recommend new language proficiency requirements. This paper focuses on the type of data that influenced this effort to reduce accidents involving the "language barrier". It also proposes to better define and record the linguistic factors in databases. A literature review on the main linguistic contributory factors to air-ground miscommunications breaks them down into sub-categories. Subsequently, the paper discusses the "language barrier" as a potential "safety barrier". It seems essential to better track and record these successful safety barriers (or nets) related to human behaviors. They should be expanded through a "positive" taxonomy that would ultimately help in evaluating the resilience of the aviation system.

## Introduction

After a fatal Runway Incursion that occurred on May 25, 2000 at Paris Charles de Gaulle, the BEA recommended that:
"*in the light of the analysis of this accident and previously acquired experience, the DGAC study the expediency and methods of implementation for the systematic use of the English language for air traffic control at the Paris Charles de Gaulle aerodrome, as well as the extension of this measure to other aerodromes with significant international traffic.*" (BEA, 2002)

Although the report had stressed that the investigation did not aim to evaluate the advantages and disadvantages of the systematic use of a single language, this recommendation has often been misinterpreted. This paper will put emphasis on linguistic factors from different perspectives.

It will first consider how to link linguistic factors to accident data stored in the Accident/Incident Data Reporting system (ADREP) system operated by the International Civil Aviation Organization (ICAO). Some statements have oversimplified communication problems and suggested a link to inadequate language skills without any analysis. The next part will elaborate on linguistic factors by proposing some definitions and by studying how they could be better recorded and tracked in databases to facilitate safety analyses. Finally, as the aviation system has been moving from a reactive paradigm to a more proactive data-driven paradigm, it seems essential to record and analyze both the strengths and weaknesses of the system. From a broader perspective, data-driven safety measures should take into account the resilience of some safety nets, such as successful behaviors, that prevented an incident from turning into an accident. This paper will also address how linguistic safety nets could be a subset of a positive taxonomy geared to better record the resilience of the aviation system.

## Accidents and linguistic factors

Recent statements tying accidents to poor language proficiency highlight a need for new regulations on English proficiency: "*[…] concern grew over English language proficiency as a result of some high profile accidents and incidents. Between 1976 and 2000, more than 1,100 passengers and crew lost their lives in accidents in which investigators determined that language had played a contributory role*" (Matthews, 2004). These concerns contributed to implementing higher standards at an international level.

The following review is not intended to downplay the role of language proficiency for aviation safety, but is seen as an opportunity to better define, record and ultimately analyze data on linguistic factors. Among the well known accidents[1] referred to when safety is tied to language issues, linguistic factors never appear as the "central" cause. They were generally considered as contributory factors under the broad term of "communication". Investigation authorities seldom explicitly cite language issues in their conclusions (in section 3 of the standardized format of ICAO Annex 13 Final Reports). These issues are more often found in the section related to the analysis (section 2).

[1] - Aircraft Collision: Boeing 747, PH-BUF, KLM and Boeing 747, N737PA, Pan Am, Los Rodeos (Tenerife), March 27, 1977.
- Fuel Exhaustion: Avianca Flight 052, Boeing 707, HK-2016; Cove Neck, New York; January 25, 1990.
- Controlled Flight Into Terrain: American Airlines Flight 965; Boeing 757, N651AA; near Cali, Colombia; December 20, 1995.
- Etc.

The final report on the accident that occurred on August 14, 2005, to a Boeing 737 operated by Helios Airways is a good example. The German pilot and the Cypriot co-pilot did not identify the aural pressurization alarm. They continued climbing with a non-pressurized aircraft and became incapacitated due to hypoxia. In the analysis part of this report, the commission stressed that: "*as English was not the Captain's native language and under the influence of stress, this possibility could not totally be ruled out. […] Also, human performance, and particularly memory, is known to suffer from the effects of stress, thus implying that in a stressful situation the search and choice of words to express one's concern in a non-native language can be severely compromised*" (AAIASB, 2006). However, the conclusions of this report do not mention the "language barrier" as a possible contributing factor neither in the direct causes, latent causes nor in the contributing factors to this accident.

The piece of information stressed in the analysis is worth being recorded in the ADREP data report, the report that States are required to send to ICAO for data dissemination and accident prevention purposes. A future query on linguistic factors will accordingly retrieve this accident in the example of a study on stress and language. This emphasizes the need to use a common methodology for investigation and data collection which could allow better integration of human issues. The latest ADREP taxonomy version developed by ICAO contains a causal model that supports and articulates active and organizational deficiencies.

ADREP taxonomy

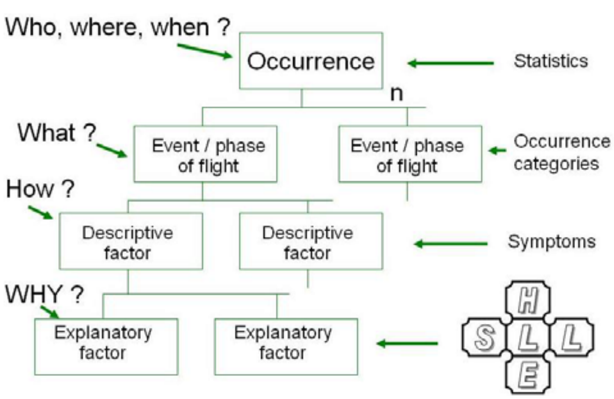


***Figure 1.*** ADREP /SHELL causal structure tied to the investigation questions

The ADREP structure (Figure 1), which was initially based on a sequence of events in the seventies, was completed in the eighties by descriptive and explanatory factors, thus introducing active or latent factors. Finally, in its latest version (ADREP 2000), the SHELL[2] model was integrated at the level of the explanatory factors to cover the aviation system. This multilayered structure gives flexibility in analyzing system failures. Indeed, the SHELL items are also presented in tree lists (Figure 2) and each item can be applied from the sharp end to the blunt end (on persons or organizations, i.e. respectively recording active or systemic failures). In ADREP 2000, investigators can code as many events ("n") and factors as needed to record and analyze an accident or an incident. Descriptive and explanatory factors can be refined by modifiers.

**Current linguistic factors in ADREP 2000**

There are currently three ways of recording linguistic factors identified during an investigation in the ADREP system. First, the term "*not understood - language barrier*" is available as a modifier both at the descriptive and explanatory levels. Then, the SHELL items (i.e. at the explanatory level) contain two keywords ("*language*" and "*accent*") related to linguistic factors (Figure 2).

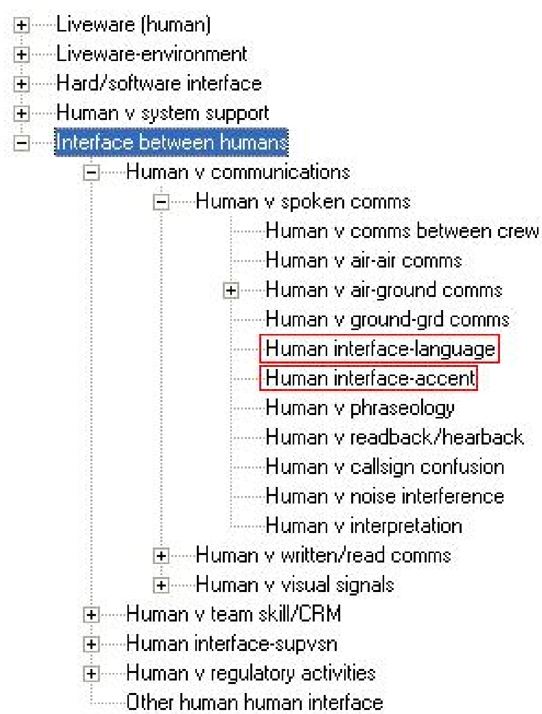


***Figure 2***. SHELL Model - language and accent factors

[2] SHELL: Software (procedures, symbology, etc.), Hardware (machine, ergonomics, etc.), Environment and Liveware (human) (Edwards, 1972 modified by Hawkins, 1987).

Eurocontrol recently used the SHELL model to analyze spoken communications between air traffic controllers and flight crews (Van Es, 2004). The interface L-L is between the controller and the pilot in charge of radio communications (Figure 3). The controller and the pilot have interfaces with their own environment, hardware, and software blocks. For instance, a pilot cannot have an interface with the controller's hardware.

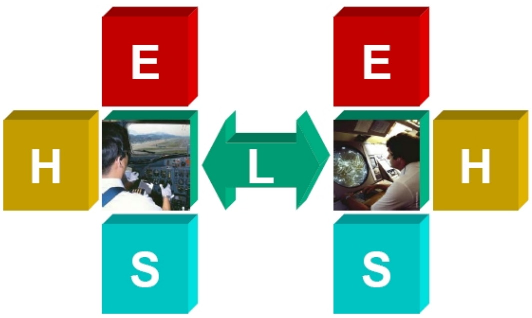


***Figure 3.*** Illustration of pilot and ATC interface

In a follow-up study, Eurocontrol organized a reporting campaign with questionnaires sent to airline pilots and air traffic controllers to determine the situation in Europe (Van Es et al, 2006). Regarding the main surveyed communication problems, 344 pilots and controllers reported both:
- linguistic factors such as accent, speech rate, ambiguous phraseology (see table) and
- non linguistic factors such as distraction, fatigue, workload.

| Problems | Contributing factors |
|---|---|
| Similar call sign | Controller accent (34%), Controller speech rate (28%), Pilot distraction (22%), Pilot expectation (25%) and Pilot fatigue (20%) |
| Frequency change | Controller accent (51%), Controller speech rate (42%), Pilot distraction (43%), Pilot fatigue (35%) and Pilot workload (31%) |
| Non standard phraseology | Controller (64%) and pilot (41%) non standard phraseology, Controller accent (49%), language problems (46%), Ambiguous phraseology (41%) |
| Blocked transmission | Frequency congestion (63%), Controller workload (33%), Untimely transmission (27%), Pilot workload (22%), Long message (20%) |

This table ties language problems to non-standard phraseology and also mentions controller accent as a recurrent factor.

**Querying repositories using the ADREP taxonomy**

A query based on the ADREP/SHELL linguistic factors was built with ECCAIRS[3]. It was applied on various databases (BEA, EASA and ICAO) that are all using the ECCAIRS software, which is ADREP 2000 compatible (Menzel, 2004). The query returned mixed results. The number of occurrences was relatively low (between twenty and thirty). Only one of the “well known” occurrences was retrieved. This was the case of the Paris Runway collision that was analyzed and simultaneously coded in the process of the investigation. On the positive side, other interesting cases came out; recent occurrences appear to have been investigated and analyzed with a methodology based on the ADREP 2000. Interestingly, the related reports were retrieved from the three repositories queried. This also shows that data exchange through the ADREP system using a common tool (ECCAIRS) is becoming a reality.

The ADREP/SHELL structure allows to describe and to explain in details the various interfaces for any occurrence. On the other hand, its complexity has often deterred end-users from coding in depth the factors of an accident or incident. The use of a methodology that addresses the various factors in the course of an investigation can overcome this issue. When applied, the clear breakdown of occurrences into events and factors allows to better tackle systemic issues; 1) for short term goals, to draft and release consistent reports and to support convincing safety recommendations; 2) for a long term objective, to capture in a structured way (in databases) the key factors and the lessons learned for future safety analyses (Ferrante et al, 2004).

**Focus on linguistic factors**

As mentioned in the Eurocontrol findings the line between phraseology and language seems blurry although it is clearly segregated in the ADREP taxonomy. Linguistic factors could be broken down into five sub-categories: context and expectations, code switching, speech intelligibility, paralinguistic factors, aviation English jargon ambiguities.

[3] **ECCAIRS**: European Co-ordination Centre for Aviation Incident Reporting Systems. ECCAIRS release 4 is a database system developed by the European Commission (Joint Research Centre located in Ispra, Italy) that supports the ADREP 2000 taxonomy. http://eccairs-www.jrc.it/Start.asp

**Pragmatics: Context and expectations**

Pragmatics is a branch of linguistics concerned with bridging the explanatory gap between sentence meaning and speaker's meaning. For Grice (1989), the crucial feature of pragmatic interpretation is its "inferential" nature: the hearer is seen as constructing and evaluating a hypothesis about the speaker's meaning, based, on the one hand, on the meaning of the sentence uttered, and, on the other, on background or contextual assumptions and general communicative principles which speakers are normally expected to observe. Context here must be interpreted as "situation" as it may include any extralinguistic factor, including discourse, social, environmental, and psychological factors.

In the Tenerife collision between KLM Boeing 747 and Pan American Airways Boeing 747, the KLM pilot understood "you are cleared to take-off" when a few seconds earlier the tower controller said: "KLM eight seven zero five you are cleared to the Papa Beacon, climb and maintain flight level nine zero, right turn after take-off…". For the controller it was the instruction following a take-off clearance that was still to come.

**Code switching**

The Tenerife collision is also an example of code switching, when the KLM pilot radioed, "we are at take-off" to express take-off instead of the standard phraseology "Taking-off". The controller interpreted that literally, indicating a place, the "take-off point" waiting for further instruction and so did not warn the pilot that Pan American Airways B747 (invisible in thick frog) was already on the runway. The Dutch speaking pilot switched into Dutch grammatical construction while keeping English words. The form of a verb that is expressed in English by the suffix "ing" happens to be expressed in Dutch by the equivalent of the infinitive (Cushing, 1995).

Code switching is a term in linguistics referring to alternation between two or more languages, dialects, or language registers in the course of discourse between people who have more than one language in common. Sometimes the switch lasts only for a few sentences, or even for a single phrase. Code-switching often occurs in bilingual communities or families. Code-switching within a sentence tends to occur more often at points where the syntaxes of the two languages align; thus it is uncommon to switch from English to French after an adjective and before a noun, because a French noun normally "expects" its adjectives to follow it. The same is true for switching from French to English after a noun and before an adjective. Code-switching between a subject and its verb is more likely, because both English and French normally place the subject before the verb.

**Speech intelligibility**

The ICAO language proficiency requirements apply to native and non native speakers alike. English today is spoken by more non-native speakers than native speakers. The focus has to be put not only on the intelligibility of non-native speakers to native speakers but also on the interaction between non-native speakers. The intelligibility of non-native speakers depends on the extent to which their languages share phonological and grammatical features. The phoneme differences between languages result in situations where distinct phonemes in one language are interpreted as being the same by foreigners. For example Japanese speakers cannot detect the difference between /r/ and /l/ sounds and cannot make the distinction when speaking English. As a consequence native speakers of these languages are quite unable to perceive the difference in English unless they have made a special effort to learn to do so. Therefore, according to ICAO, English native speakers have to familiarize themselves with the dangers of cross cultural communications (Mathews, 2004).

**Paralinguistic factors (e.g. intonation, stress)**

Paralinguistic factors can change the form and the meaning of a sentence by acting across individual sounds or words of the sentence. The Avianca 052 accident investigation indicated that ATC did not perceive the severity of the fuel crisis aboard AV052 and therefore did not treat the situation as an emergency. Intonation and pitch have a critical role in communication (Fegyveresi, 1997). Under stress or complex situations, speech becomes more rapid and more frequent. The change in pitch, which can cause "slips of the tongue", is also a sign of a stressful environment or high task complexity (Prinzo and Britton, 1993).

**Aviation English jargon ambiguities**

*Aviation parameters meaning*-The numbers used in pilot-controller communication are shared by multiple aviation parameters: flight level, heading, air speed, airline flight number. The overlapping number ranges can lead to misunderstandings, especially under high workload pressure. For example, an aircraft was flying on a heading of 300 degrees at FL270; the controller vectored it to "three one zero"; the pilot acknowledge "three one zero" and climbed to FL310 instead of turning to a course of 310 degrees (Cushing, 1995). A full readback would correct the misunderstanding in this instance.

This kind of confusion is aggravated when an ATC single message includes two or more sets of numbers. Mishearing numbers has occurred most frequently when single, one sentence clearance messages call for two or more separate pilot actions, such as "cross XYZ at one thousand, descend and maintain one zero thousand, reduce speed to 250 knots…" In the Eurocontrol survey, pilots and controllers think that a frequency change is often erroneously copied when it is part of a long message; it is recommended to limit the number of instructions per call and to issue a frequency change as a single instruction (Van Es et al, 2006).

*Homophones, homographs, synonyms and homonyms*-Some pilot-controller communication errors arise from the pronunciation of different words that sound almost alike or exactly alike such as "to" and "two" (homophones). For example: ATC cleared the aircraft to descend "two four zero zero". The pilot read back "ok. four zero zero". The aircraft then descended to 400 feet instead of 2400 feet.
Based on examination of accident investigations and incident reports, Orasanu, Davison and Fisher (1997) summarized how ineffective communication can compromise aviation safety in three basic ways: 1) Wrong information may be used; 2) Situation awareness may be lost; 3) Participants may fail to build a shared model of the present situation. Along with the increasing volume of international traffic, the risk of communication errors escalates even further because of participants' culture and native language differences (Orasanu et al, 1997).

## Triggering factors and safety nets

In 1998, India formally called on the ICAO Assembly to take action to ensure that pilots and controllers "are proficient in conducting and comprehending radiotelephony communications in the English language". In its proposed resolution, India specifically cited the 1995 Controlled Flight Into Terrain (CFIT) accident in Cali, Colombia, and the midair collision near Delhi as having indicated "lack of proficiency and comprehension of the English language by flight crews and air traffic controllers" (FSF, 2006).

The paradox is that, in the public report produced by India (Government of India, 1997), only one factor is mentioned: "*Pilot - Disregard of ATC instructions by the Kazak aircraft*". No reference to language proficiency is explicitly stressed whereas it is deemed causal in the Indian Assembly resolution. In the other accident (B757 Cali) cited in this resolution, the controller told the investigators that "*had the pilots been Spanish-speaking, he would have told them that their request made little sense and that it was illogical and incongruent. He said that because of limitations in his command of English, he was unable to convey these thoughts to the crew*." (FSF, 2006)

Adequate language proficiency could have constituted an effective safety net in the Cali accident. So far, language has generally been considered negatively through accidents and the term "language barrier". Seldom has it been seen positively as a "safety barrier" or a "safety net". A language barrier does not necessarily result in unsafe operations, although language and cultural diversity can intensify differences and confusions in communication (Hörmann, 2001). Merritt and Ratwatte (1997) conducted a study to compare safety performance between mono- versus multi-cultural cockpits. They found that although language barriers and cultural differences are inhibiting the open communication and team fellowship, multi cultural crews, especially crewmembers with English as a second language had to concisely verbalize their intent and requirements and perform "by the book". This led to rule-based behavior, with a high degree of Standard Operating Procedures (SOPs) being used.

## Towards a positive taxonomy

Language issues will have to be better documented in the future because of the international nature of aviation that keeps growing at a fast pace. Authorities may have to decide about implementing the systematic use of the English language for radio communications in areas with significant international traffic. In such cases, a risk analysis should also take into account the times when the use of the local language prevented a misunderstanding on a non-native speaker from turning into a hazardous situation. To have a more complete picture of the reality of operations, the reporting system must flag and record the safety nets, such as the use of another language, which prevented accidents.

Ad-hoc taxonomies for what went right would give a better picture for the safety role of language in aviation. Like for the negative aspects of the "language barrier", Human Factors have generally been considered in relation to accident causes or as performance limitations. However, there has been some work on: 1) considering the human factor as a safety factor, 2) recording successful human interventions in databases and 3) capitalizing on positive taxonomy to increase the resilience of the aeronautical system (Boudou et al, 2006). A positive taxonomy encompassing linguistic factors would complete proactive and data-driven initiatives that focus on incidents instead of accidents.

## Conclusion

Linguistic factors represent a vast domain for safety analyses. The ADREP taxonomy currently highlights the "language barrier", "accent" and "language". They could possibly become more detailed with sub-categories (context and expectations, code switching, speech intelligibility, paralinguistic factors, aviation English jargon ambiguities) and/or their definitions at the level of the usage notes could be completed to facilitate their codification. Nevertheless, the current taxonomy is sufficient enough to describe and explain what went wrong. On the other hand, the safety nets (e.g. third party intervention, use of native language) that saved the day need to be categorized and recorded.

The difficulties encountered in analyzing linguistic data both at a clinical level (on an accident case) or at an epidemiological level (on a wider set of reports) can be expanded to other types of safety analyses that focus on contributing factors. Data-driven initiatives first need data (i.e. coded information), ideally data recording the strengths and weaknesses of the aviation system. These data must be based on facts, which should be recorded in a consistent manner. Finally analytical tools must take into account a logical cause and effect relationship in order to produce convincing findings. Therefore, data-driven safety initiatives should always consider its origin, quality and consistency. This highlights the need to have a global approach to ultimately producing consistent data to give decision-makers a more complete picture of the aviation system, such as the pros and cons of the systematic use of the English language for air traffic control.

## References


Air Accident Investigation & Aviation Safety Board (2006). Aircraft Accident Report on Helios Airways Flight HCY522, Boeing 737-31S, at Grammatiko, Hellas, on 14 August 2005. Hellenic Republic. Ministry of Transport & Communication.

Boudou, B., Pouliquen, Y., Ferrante, O. (2006). Towards a Human Factor "Positive" Taxonomy for Occurrence Analysis. In: Proceedings of the International Conference on Human-Computer Interaction in Aeronautics, HCI-AERO, September 20-22, 2006, Seattle, pp 48-55.

Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (2002). Accident on 25 May 2000 at Paris Charles de Gaulle (95) to aircraft F-GHED operated by Air Liberté and G-SSWN operated by Streamline Aviation. From http://www.bea.aero

Cushing, S. (1995). Pilot-Air Traffic Control communications: It's not (only) what you say, it's how you say it.- Flight Safety Foundation.- Flight Safety Digest, vol. 14, n° 7, 1995.

Fegyveresi, A.E. (1997).- Vocal cues and pilot / ATC Communications. In: Proceedings of the Ninth International Symposium on Aviation Psychology, April 27-May 1, 1997, Edited by R.S. Jensen and L.A. Rakovan, Volume 1, pp. 81-84.

Ferrante, O., Jouniaux, P., Nicolas, G., Loo, T., Cabon, P., Mollard, R. (2004). Application of ADREP 2000 taxonomy for the analysis and the encoding of aviation accidents and incidents: a human factors approach. Human Factors and Aerospace Safety 4 (1), pp. 19-48.

Flight Safety Foundation Editorial Staff (2006). "High Stakes in Language Proficiency". Volume 25. January-February 2006.

Government of India (1997). Civil Aviation Aircraft Accident Summary for the Year 1996. Directorate General of Civil Aviation DGCA: Ministry of Civil Aviation 1997.
From http://dgca.nic.in/aircraft/acc-ind.htm

Grice, H. P. (1989) Studies in the Way of Words, Cambridge, MA.

Hawkins, F. H. (1987). Human Factors in Flight. Aldershot, United Kingdom: Gower Technical Press.

Hörmann H.-J., Cultural variation of perceptions of crew behavior in multi-pilot aircraft, Le travail humain 2001/3, Volume 64, pp. 247-268.

Mathews, E. (2004). New provisions for English language proficiency are expected to improve aviation safety. ICAO Journal, vol. 59, 1, 2004, pp. 4-6.

Menzel, R. (2004). ICAO safety database strengthened by introduction of new software. ICAO Journal, vol. 59, 3, 2004, pp. 19-26.

Merritt, A., Ratwatte, S. (1997). Who Are You Calling A Safety Threat ? A Debate on Safety in Mono- Versus Multi-Cultural Cockpits, International Symposium on Aviation Psychology, pp. 661-666.

Orasanu, J., Davison, J. and Fisher, U. (1997). What Did He Say ? Culture and Language Barriers to efficient Communication in Global Aviation. In: Proceedings of the International Symposium on Aviation Psychology, pp. 673-678.

Prinzo, O.V., Britton, T.W. (1993). ATC / Pilot Voice Communications. A Survey of the Literature. Federal Aviation Administration Report DOT/FAA/AM-93/20, November 1993.

Van Es, G.W.H., Eurocontrol (2004). Air-ground Communication Safety Study: An analysis of pilot-controller occurrences. Eurocontrol, June 16, 2004.

Van Es, G.W.H., Wever, R., Verbeek, M., Eurocontrol (2006). Air-ground communication safety study: Causes and Recommendations. DAP/SAF 2006-09. Eurocontrol, January 16, 2006.