DO LANGUAGE BARRIERS RESULT IN AVIATION MAINTENANCE ERRORS?

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The existence of maintenance and inspection personnel whose native language is not English suggests that language barriers may be causing performance errors. This project examines whether such errors exist, what patterns characterize these errors, what their contributing factors are and how effectively we can mitigate these errors. Any language errors would be communication errors by definition, so first we reviewed models of communication to search for characteristic error patterns. We identified two primary communication types relevant to aviation maintenance: synchronous communications (largely verbal and informal) and asynchronous communication (largely written and formal). We then analyzed several error databases (e.g. ASRS) and found that both the contributing factors and the use of recovery mechanisms were different for the two error types. Next, we analyzed survey data from 113 aircraft operators, covering their English speaking/reading abilities and use of mitigation strategies. There were significant differences across four world regions in the incidence of these two sets of factors. Neither of these data sources emphasized maintenance, so to discover more refined patterns of error, contributing factors and mitigation strategies, we conducted a series of focus groups at maintenance organizations. The patterns found were grouped, as expected, into synchronous and asynchronous. We developed classified lists of contributing and mitigating factors, which will be used in subsequent stages to quantify error incidence and test the effectiveness of mitigation strategies.

INTRODUCTION

Outsourcing is a preferred corporate strategy for reducing nonessential costs and focusing an organization on its core business (Cant and Jeynes, 1998). In aviation maintenance, outsourcing has been advocated and widely used, as it avoids tying up capital in maintenance facilities, and can reduce costs by opening the airline's maintenance operation to outside competition. One potential impact of such outsourcing is that there are more interfaces within the system, each of which represents an opportunity for error. The "system" without outsourcing includes the aircraft itself, the airline and the regulatory agency (e.g. the FAA). However, with outsourcing, a fourth organization is added to the system: the Maintenance/ Repair Organization (MRO). Drury, Wenner and Kritkausky (2000) provided models of these interactions and examined potential and actual error sources from using MROs. Data collection at a number of domestic and foreign MROs did indeed show a potential for increased errors, but little evidence of errors in practice.

Sparaco (2002) sees the formation of global MRO networks involving US and foreign airlines, as well as repair stations. In addition to offshore MROs, there are many within the USA where non-native English speakers form part of the labor pool. The difficulty of moving between languages creates an additional potential for error. The language of aviation is primarily English, both in operations and in maintenance. Aviation Maintenance Technicians (AMTs) must pass their examinations in English, and maintenance documentation in use at the Federal Aviation Administration (FAA) approved facilities is in English. This poses a second-language or translation burden for Non-Native English Speakers (NNESs) that can potentially increase their workload, their performance time or their error rate, or even all three measures.

In a 2001 report to the Secretary of Transportation by the Aircraft Repair and Maintenance Advisory Committee, many of these issues were raised in considering changes to the domestic and foreign FAR Part 145. They recommended that:

> "The FAA should establish a method for determining whether language barriers result in maintenance deficiencies."

This project is a direct response to these concerns that NNES, in repair stations in the USA and abroad, may be prone to an increased error rate that could potentially affect airworthiness.

MODELS OF COMMUNICATION

Communication is defined as "a dynamic and irreversible process by which we engage and interpret messages within a given situation or context, and it reveals the dynamic nature of relationships and organizations" (Rifkind, 1996). Communication can be formal or informal. Davidmann (1998) made a distinction between formal and informal communication, where formal communication implies that a record is kept of what has been said or written, so that it can be attributed to its originator. On the whole, written communications are formal. Most on-the-job communication is informal, unwritten, and sometimes even unspoken. An important distinction made in communication theory is the temporal aspect: communication is either synchronous or asynchronous. In aviation maintenance, synchronous communication is typically verbal, e.g. conversations or PA

announcements, while asynchronous communication is typically written, e.g. work documentation or placards. In the context of aviation maintenance and inspection, communication has been the most frequent aspect studied since the human factors movement began there in the early 1990's (Taylor and Patankar, 2000).

The fundamental function of communication is to deliver a message from one human being to another. In almost every aspect of aviation work, communication also fulfills a secondary role as an enabler (or tool) that makes it possible to accomplish a piece of work (Kanki and Smith, 2001). Based on examination of accident investigations and incident reports, Orasanu, Davision and Fischer (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 at a team level.

Communication models in the form of generally simple diagrams are important in helping people to understand the concept and process (Wideman, 2002). Kanki and Smith (2001) state that human communication always takes place within a set of contexts, such as a social context, a physical context and/or an operational context. Compared to some other work settings, the aviation operational context is relatively structured by standard operating procedures that organize task performance. Figure 1 presents a communication model we synthesized from our literature review.

Based on basic communication theories, a communication process is composed of *the sender/receiver* (e.g. people, manuals, computers, etc.), *the message* (e.g. information, emotions, questions, etc.), the *medium* (e.g. speech, text, sensory, etc.), *filters/barriers*, *feedback*, etc. (Kanki and Smith, 2001; Griffith, 1999).

Fegyveresi (1997) summarized many variables that influence communication, such as workload, fatigue, personality traits, gender bias, standard phraseology, experience level, vocal cues, etc. Language and cultural diversity can intensify differences and confusions in communication, but a language barrier does not necessarily result in unsafe cockpit operations (Merritt and Ratwatte, 1997). In order to eliminate or at least minimize potential ambiguities and other variances, people establish rules regarding which words, phrases, or other elements will be used for communication, their meaning, and the way they will be connected with one another. The aggregation of these rules is known as a "protocol." There are four types of protocol related to flight and aircraft safety (Rifkind, 1996a&b): verbal, written, graphical, and gestural protocols. According to Rifkind (1996a&b), the only verbal protocol that has been established throughout aviation, including maintenance, is the use of English as the standard language. This was done when the International Civil Aviation Organization (ICAO) was established in 1944.

CURRENT DATA SOURCES

Before field data is collected on language-related maintenance and inspection errors, existing databases need to be searched for relevant reports of such errors. The most useful of these were the NASA/FAA Aviation Safety Reporting System (ASRS) and the Accident/Incident Data System (AIDS). Our main interest was in maintenance and inspection errors, but few were reported in the databases studied. Hence, our objective changed to include all language-related errors, whether by flight crew, ATC, cabin crew or ground crew. This decision was in line with our literature search, which we broadened to include all communication errors. With a large enough set of aviation-related language errors, we can form more general models, of which maintenance and inspection errors will be a specific instance.

Based on a preliminary reading of about 60 incident reports, a taxonomy was developed of error manifestations, causal factors and recovery mechanisms. Some entries in this taxonomy reflect the earlier analysis by Orasanu, Davision and Fischer (1997), although we have tried to separate contributing factors from recovery mechanisms. This preliminary reading also found likely key words for searches. Two keyword searches were made of the ASRS and AIDS databases. The first was on "English" and the second on "Language." We classified 684 incidents by *error type*, *contributing factor*, and *recovery mechanism*. Details are not presented here due to space limitations.

The main division of error types was between synchronous and asynchronous communication. Within these, a relatively fine classification was made by the roles of the two communicators, e.g. flight crew with ground crew. This classification was eventually collapsed into four categories. Note that "language" was used to refer to two items. Language could mean the actual language used (e.g. French, Spanish, Chinese, English) or the choice of words/phrases (e.g. listener expected one term but communicator used what was incorrectly thought to be a synonym). Some of the communication channels themselves were poor, classified here as low signal/noise ratio. In many cases, the report mentioned that at least one of the communicators was inexperienced, for example an American crew's first flight for some years into a Mexican airport.

The analysis of the ASRS and AIDS databases used a cross-tabulation technique developed by Wenner and Drury (2000) to show significant and often interesting conclusions in Figure 2 and Figure 3. When the error locus was classified by the roles of the communicators, differences in contributing factors and recovery mechanisms were seen. Our four categories of causal factors gave roughly equal counts in the databases, showing that the use of other than a native language was an important causal factor in these errors. This contributing factor appeared to be distributed across error loci, except for asynchronous communication, where it was under-represented. In fact, for asynchronous communication as a whole, native language and low signal/noise ratio were under-represented factors, while unclear terminology was over-represented. For recovery, asynchronous communication had the least opportunity for recovery mechanisms. In particular,

the repetition useful in synchronous communications was not usually fruitful.

The characteristics of maintenance communications errors found here (asynchronous, terminology-related, few recovery mechanisms) helped to set the stage for our direct measurement of these errors from maintenance participant interviews and questionnaires.

From September 2002 to January 2003, an international corporation surveyed a large number of airlines throughout the world concerning their use of English and other languages in flight operations and maintenance operations. The database used was based on a large sample (n = 113) of airlines, approximately evenly divided between North America, Europe, Asia and the rest of the world. Analysis of the use of English in written and spoken communications showed that English is spoken and read at a high level in North America, and to a large extent (75% or so) in Europe. In contrast, Asia and the other countries have about 50% of users able to work with written English effectively, and about 30-40% able to work with spoken English in the same way. The data from each level of English Speaking/Reading ability were analyzed separately using one-way ANOVAs among the four regions. All levels showed significant differences between regions.

The airlines cope with any potential problems through a number of means, including document translation, and conducting training and meetings in native languages. We have found that in Europe and North America, such strategies were infrequently used, presumably because most mechanics speak English, even if that is not their native language. In contrast, Asia and the rest of the world make significant use of these strategies. Translation of documents was not a common strategy, except for Asia, where 17% of airlines translated Task Cards and 60% translated Engineering Orders. Comparable figures were about 4% and 20% of airlines in other parts of the world, and almost nobody translated the Maintenance Manual. The strategy of using the native language in speaking was widely seen, with almost all Asian airlines and most airlines in other non English-speaking countries conducting meetings and maintenance training in languages other than English. However, this may represent a mismatch to documentation used in the same task that typically remained in English.

We expected that those airlines with low levels of English-reading ability would adopt some mitigating strategies in using the original documents (i.e. modification into AECMA Simplified English, translation into their native language). However, when using the Maintenance Manual, 7 out of 8 kept the original documents in English without any modification or translation, while only one airline modified/rewrote it in English. When using the Structural Repair Manual, 6 out of 8 airlines did not make any modification or translation. For those airlines with a low level of English-speaking ability, 100% conducted Onsite Maintenance Training in a language other than English (i.e. the native language). In Meetings, 10 out of 12 airlines used another language, while the remaining two used both English and another language. Again, during Casual Talking, none of the airlines used English.

FOCUS GROUPS ON LANGUAGE ERRORS

While the analysis of archival data in the above section could provide some insight into language errors in maintenance, such data were not collected for that purpose (c.f. Drury 1995). More direct data collection involves the use of questionnaires and interviews specifically on the theme of language errors in maintenance. However, before we can ask sensible questions, we must have valid information on the types of errors involved. We collected such data from focus groups at MROs in different countries. So far (May 2003), we have run five such focus groups, three at US-based MROs and the other two at UK-based MROs.

A focus group gathers people together to discuss the issue at hand via moderator questions and group discussions. Data are gathered through observations and conversations with participants. Focus groups are particularly appropriate for use in exploratory studies when little is known about a population or phenomenon. According to Albrecht et al. (1993), data collected in focus groups may be more ecologically valid than methods that assess individuals' opinions in a relatively asocial setting, given that language errors are social events involving the interaction of participants and the interplay and modification of ideas.

We used focus groups of people at MROs drawn from AMTs, supervisors, engineers and QA specialists. Each interview lasted about 45 minutes. Our introductory statement (after introductions, ground rules and assurance of anonymity) was:

> "We are helping the FAA to reduce errors in aviation maintenance and inspection. Our aim is to find improved ways of performing maintenance and inspection jobs. One issue has been that although English is the primary language of aviation, many people do not have English as their native language."

Then, the focus groups discussed approximately ten questions with the principal investigator as moderator. When we had transcribed the data, we compared the transcripts with our notes to look for patterns of maintenance language errors or events under four headings.

1. Error types/patterns
2. Potential error detection points in the maintenance process.
3. Factors predisposing to language errors
4. Factors potentially mitigating language errors

From these lists, we were able to see the functions of aircraft maintenance and inspection (see Drury, Shepherd and Johnson, 1997) and where language errors could arise. **Table 1** represents our current characterization of these situations where their errors could arise, presented within a task sequence framework. We found the following patterns of error in both verbal (synchronous) and written (asynchronous) communication.

Verbal (Synchronous)
1. AMT unable to communicate verbally to the level required.

2. AMT and colleagues/supervisors have poorly matched models of their own and each other's English ability.
3. Native English speakers with different regional or non-US English accents (e.g. UK, India, Caribbean) prevent adequate communications.
4. AMTs unable to understand safety announcements over the PA system.

Written (Asynchronous)

5. AMT unable to understand safety placard in English.
6. AMT unable to understand written English documentation.
7. Foreign documentation poorly translated into English.

While the patterns are still being refined as further data is collected, and may eventually exhibit more of a hierarchical structure, they were reasonably consistent between the focus groups studied.

Table 2 shows the predisposing and mitigating factors identified in the focus groups. They are classified in terms of the SHELL model of human factors in aviation (Easterby, 1967).

NEXT STEPS

The first phase of our project was to find the patterns of language errors, provided there is evidence that they exist. Our analysis of communication models and the company database has shown the potential for language errors by showing that responses to language differences may not always keep pace with the need for such interventions. The ASRS database analysis showed some actual errors, although these were mainly in the flight operations domain more likely to be reported to ASRS. Patterns in this data showed that maintenance language errors were largely asynchronous, while related to terminology and had few recovery mechanisms.

The five focus groups tested so far have refined our conclusions. We now have ample evidence that language errors exist, although there are recovery mechanisms and mitigating factors. The patterns found were numerous, and certainly not limited to asynchronous communication. Although documentation was an important source of difficulty, there were other patterns in verbal communication, including unexpected ones of regional accents of native English speakers. We were also able to further document the time course and propagation of errors, including error detection points and interventions. In an industry as heavily regulated as aviation maintenance, there are a number of barriers to error propagation (c.f. Reason, 1990), including the initial work assignment and inspection by a different person.

The characteristics of language errors found so far in maintenance will be refined as more focus group data is collected, but the agreement reached to date suggests that a few overall patterns may account for most of the potential errors. In subsequent years of this project, we will be collecting field data to estimate the prevalence of the patterns we have derived. This will be done using direct data collection in several regions of the world, for example those used in our analysis of the company database. We will also use our methodology of comprehension tests of workcards (e.g. Chervak, Drury and Oullette, 1996; Drury, Wenner and Kritkausky, 1999) to test the effectiveness of intervention strategies. These include use of Simplified English, full translation, use of an English-speaking coach and provision of a local language glossary. In this way, we will be able to make recommendations to both MROs and regulatory bodies for the effective reduction of language errors.

REFERENCES

Albrecht, T.L., Hohnson, G.M., and Walther, J. B. (1993). Understanding Communication Processes in Focus Groups. *Successful Focus Groups, Advancing the State of the Art,* D. L. Morgan (Eds). Sage Publications, Inc., Thousand Oaks, CA. 51-64

Cant, M. and Jeynes, L. (1998). What does outsourcing bring you that innovation cannot? How outsourcing is seen – and currently marketed – as a universal panacea. *Total Quality Management.* 9(2/3), 193-202

Chervak, S., Drury, C. G. and Ouellette, J. L. (1996). Simplified English for Aircraft Workcards. *Proceedings of the Human Factors and Ergonomic Society39th Annual Meeting.* 303-307

Davidmann, M. (1998). *Using Words to Communicate Effectively.* Online resource: http://www.solbaram.org/articles/words.html

Drury, C. G. (1995). The use of archival data. *Evaluation of Human Work* (Second Edition), J. R. Wilson and E. N. Corlett (Eds). Chapter 5. Taylor and Francis, New York. 101-112

Drury, C. G., Shepherd, W. T. and Johnson, W. B. (1997). Error reduction in aviation maintenance. *Proceedings of the 13th Triennial Congress of the International Ergonomics Association'97.* Tampere, Finland. Vol. 3, 31-33.

Drury, C. G., Wenner, C. and Kritkausky, K. (1999*). Development of process to improve work documentation of repair stations.* FAA/ Office of Aviation Medicine (AAM-240). National Technical Information Service, Springfield, VA.

Drury, C. G., Wenner, C. and Kritkausky, K. (2000). Information design issues in repair stations. *Proc. Tenth International Symposium on Aviation Psychology.* Columbus, OH.

Easterby, R.S. (1967). Ergonomics Checklists: an appraisal. *Ergonomics.* 10(5), 549-556.

Fegyveresi, A. (1997). Vocal Cues and Pilot/ATC Communication. *International Symposium on Aviation Psychology.* 81-84.

Griffith, E. (1999). *A First Look at Communication Theory (4th edition).* Boston: McGraw-Hill.

Johnson, D.W. (1972). *Reaching Out.* Englewood Cliffs, N.J.: Prentice Hall.

Kanki, B. G., and Smith, G. M. (2001). Training Aviation Communication Skills. *Improving Teamwork in Organizations: Applications of Resource Management Training,* E. Salas, C.A. Bowers and E. Edens (Eds). Lawrence Erlbaum Associates, Mahwah, New Jersey. 95-127.

McAuley, J.G. (1970). *People to people: Essentials of Personal and Public Communication.* Belmont, CA: Wadsworth Pub. Co.

Merritt, A., and 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.* 661-666

Orasanu, J., Davison, J., and Fischer, U. (1997). What Did He Say? Culture and Language Barriers to efficient Communication in Global Aviation. *International Symposium on Aviation Psychology.* 673-678.

Reason, J. (1990). *Human Error.* Cambridge University Press.

Rifkind, L. J. (1996a). Communication in the maintenance work environment. *Meeting Proceedings Tenth Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection: Maintenance performance enhancement and technician resource management* (pp. 25-41) Federal Aviation Administration/Office of Aviation, Washington, DC. Online access: http://hfskyway.faa.gov

Rifkind, L. (1996b). Communication. *Human Factors Guide for Aviation Maintenance* (Federal Aviation Administration/Office of Aviation Medicine). Washington, DC, pp 13/1-13/54. Online access: http://hfskyway.faa.gov

Sparaco, P. (2002). French Foresee Broader, Multinational MRO Network. *Aviation Week and Space Technology*. 72-73

Taylor and Patankar (2000). The Role of Communication in the Reduction of Human Error. *Proceedings of the 14th International Symposium on Human*

Factors in Aircraft Maintenance and Inspection. Vancouver, B.C.

Wenner, C. A., and Drury, C. D. (2000). Analyzing Human Error in Aircraft Ground Damage Incidents. *International Journal of Industrial Ergonomics*. 26, 177-199

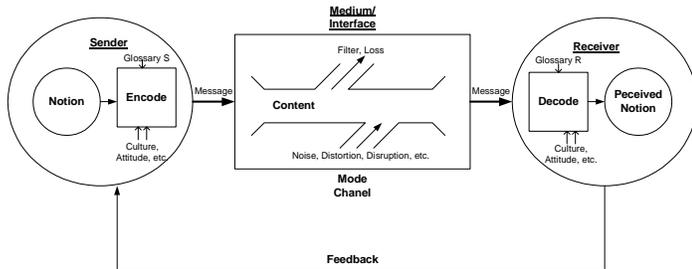Wideman, R.M. (2002). *Communication Models*. Online resource: http://www.maxwideman.com/issacons4/iac1432/

Figure 1. The Communication Model Synthesized from Literature Review (Wideman, 2002; Threnholm, 1986; McAuley, 1979; Johnson, 1972,etc.)

Function	Language Error Detection
Setup	• AMT may appear perplexed, or may agree with everything said.
Task Performance	• AMT may ask for assistance or clarification. • AMT may close access prematurely (i.e. before buyback)
Buyback	• Physical error may be detected. • AMT may not understand inspector's questions.

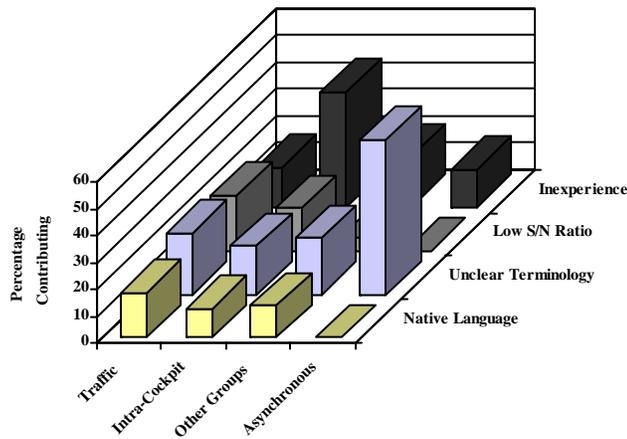**Table 1. Language Errors Arising in a Task Sequence Framework**

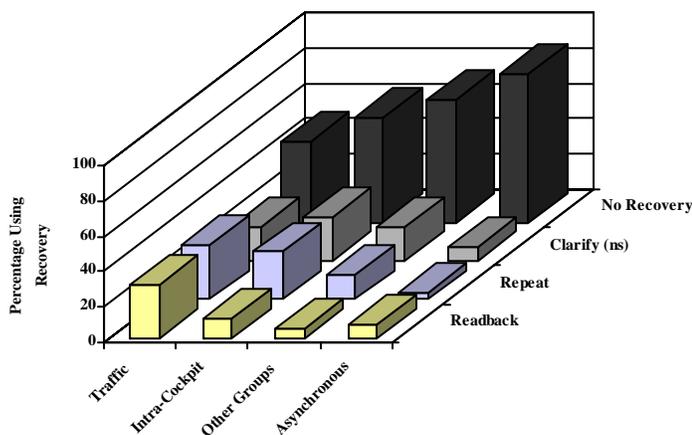**Figure 2. Pattern of Contributing Factors across Error Loci**

SHELL Category	Predisposing Factors	Mitigating Factors
Software (procedures)	• Task complexity • Instruction complexity	• Document translation • Consistent terminology • Good document design
Hardware (equipment)	• Limitations of communication channel, e.g. radio, PA	• Use of aircraft as a communication device: "show me"
Environment	• Time pressure prevents AMT from querying others	•
Liveware (individual)	• Inadequate written English ability • Inadequate English ability • Reversion to native language under stress	• Job familiarity • Comprehension tests for AMTs • Certify AMT for specific jobs
Liveware (inter-communication)	• Unwillingness of AMT to expose their lack of English • Time pressure	• Translator available • Assign AMTs to job based on English ability • Team AMT with native English speaker

Figure 3. Pattern of Recovery Attempts across Error Loci

Table 2. Predisposing and Mitigating Factors Identified in the Focus Groups