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Pilot English Language Proficiency and the Prevalence of Communication Problems at Five U.S. Air Route Traffic Control Centers

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16. Abstract

Air traffic control (ATC) voice communication is built upon a readback-hearback loop: Controllers send messages to pilots who listen and then recite back their contents. Successful communication requires participants to conduct and understand ATC radiotelephony in the same language. Since inadequate language proficiency was involved in some aviation accidents (e.g., 1996 Charkhi Dadri; 1995 Cali; 1977 Tenerife), the International Civil Aviation Organization (ICAO) is requiring its contracting states to ensure that ATC personnel and flight crews are proficient communicators of the English language when operating in airspace where the English language is required. Within the U.S., data are lacking concerning the prevalence of ATC communication problems attributable to the production and comprehension of English. This report presents communication problems involving readback errors, breakdowns in communication, and requests for repetition by commercial airline pilots. An analysis was performed on 50 hrs of air-ground transmissions provided by five ARTCCs. Each controller transmission was paired with its readback. Each readback was scored for accuracy (Prinzo, Hendrix, & Hendrix, 2007). *The ICAO Language Proficiency Rating Scale* guided encoding English language proficiency. Aircraft call signs were used to classify transmissions by aircraft registry (U.S., Foreign) and language (English, Other), forming three groups: Foreign-English, Foreign-Other, and U.S.-English. Communications were analyzed from 832 aircraft (74% U.S., 26% Foreign) for 4,816 pilot transmissions (78% English, 22% Other). Of these aircraft transactions, 23% contained one or more communication problems. MANOVA and ANOVA revealed that when English was the primary language or pilots flew U.S. aircraft, there were fewer communication problems, less time was spent on frequency, and fewer messages were transmitted than when pilots flew foreign aircraft or the primary language was not English. A chi-square analysis of 276 communication problems revealed that English language proficiency was a factor for 75% communication problems among the Foreign-Other aircraft and 29% involving U.S.-English aircraft. The communication problems of the Foreign-English aircraft were excluded because of their joint classification with aircraft registry and language. Using the ICAO language proficiency scales as a guide revealed pronunciation (pilot accent) and fluency as contributing to communication problems among pilots of Foreign-Other registry aircraft.Among the U.S.-English flights, although fluency was a factor, it signaled uneasiness with an ATC instruction. The location of pauses, “AHs” and “Ums,” might differentiate less proficient speakers (markers appear within a phrase or cause) from more proficient speakers (markers appear before and after a phrase or clause). ICAO required that its language proficiency standards be implemented in March 2008. Being able to speak “Aviation English” may be necessary, but it may not be sufficient in limiting communication problems. Language proficiency requirements beyond the minimum specified by ICAO must be realized if communication problems are to decline.

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EXECUTIVE SUMMARY

The International Civil Aviation Organization (ICAO) required the implementation of its language proficiency standards in March 5, 2008, among its member states who were ready, and will extend a maximum 3-year waiver to its member states that can submit their testing program to ICAO by the March deadline. The development of these standards began as a response to an increase in aviation fatalities and accidents that cited inadequate English language proficiency as either a causal or contributing factor.

The purpose of this report is to provide some indication as to the types and frequency of communication problems experienced by pilots who may or may not have English as their primary or official language. To do this, the communications of pilots and controllers were examined that occurred between March and August 2006 at five U.S. air route traffic control centers (ARTCCs). Aircraft call signs were used to classify them as either U.S. or foreign registry, and then the official language of the country of registry was identified. Three different groups were examined: U.S.-English (n=642), Foreign-English (n=26), and Foreign-Other (non-English, n=164). We were not able to confirm the native languages of the pilots working the radio; however, by listening to the voice properties of the speakers, we were able to evaluate whether or not language was a problem in communication guided by the application of the ICAO Rating scales.

In this report, we define a communication problem as a situation in which a message is not understandable in content, speech (accent), structure, or a combination that reaches the level of interfering with traffic procedures. Notably, a communication problem may create an air traffic control (ATC) problem; however, an ATC problem (e.g., diverting aircraft away from a weather front) rarely creates a communication problem. Communication problems were encoded that resulted in interference with traffic procedures, required plain language to resolve, or required assistance from other pilots or ATC to convey the message, or the encoder believed that communication had broken down.

The communication problems were classified into three major categories: readback errors, requests for repeat, and breakdowns in communication. An examination of these communication problems showed that for U.S. registry aircraft transactions with one communication problem, 51% involved readback errors, 34% requests for repeat, and 15% breakdowns in communication. In contrast, 23% of the foreign registry aircraft transactions with one communication problem were readback errors, 62% were requests for repeat, and 14% involved breakdowns in communication. Of the transactions with multiple problems, more than 75% involved foreign registry aircraft.

To determine whether or not communication problems included messages with deficiencies in English language proficiency, an overall detailed analysis was performed on the pilot-controller transactions identified as having one or more communication problem. Generally, the encoder answered two questions: (1) Is there a communication problem? (yes or no); and (2) Was language proficiency involved? (yes or no). If the encoder believed language proficiency was involved, then an attempt was made to classify English language proficiency using the ICAO Language Proficiency Scales as a guide.

Among foreign registry aircraft, the more frequently occurring readback errors included radio frequency and route aviation topics. In 64% of the readback errors made by Foreign-Other registry aircraft pilots, their accents made it difficult for the controller to understand what was being said. For U.S. registry aircraft, the more frequently occurring readback errors involved radio frequency and altitude aviation topics, of which pronunciation was a factor for 1% of the readback errors.

Nearly 63% of the requests to repeat involved the confirmation or say again of a specific aviation topic. Foreign and U.S. registry aircraft each wanted confirmation of radio frequencies, routes, and altitudes more than any of the other aviation topics. The following message expresses several factors that influenced a pilot's rationale for a request for repeat, "I – I APOLOGIZE IT'S EARLY IN THE MORNING, AND MY BRAIN'S UH – THE PEN UH WHICH ISN'T WORKING WELL – UH YOU GOTTA READ IT AGAIN SLOWER."

Of the transactions involving a breakdown in communication, runway assignment, and route clearance transactions were especially problematic for the pilots of Foreign-Other registry aircraft. The problem may be partially due to controllers' and pilots' use of plain language and the pilots' pronunciation and fluency. Notably, accent affected the intelligibility of 40% of the pilots' messages.

The breakdowns in communication experienced by U.S.-English registry aircraft involved call sign confusion and the transfer of communication process (either a transfer occurred too soon or the controller had to initiate the call-up). Pronunciation and vocabulary rarely appeared in a breakdown of their communication.

The findings presented here revealed that when the registry of an aircraft was foreign and its primary or official language was not English, not only did pilots spend more time communicating with ATC, they also exchanged more transmissions and had more communication problems in their transactions. The additional pilot messages may have resulted from attempts to resolve some of the communication problems. In these situations, a pilot's English language proficiency — especially his/her accent — often resulted in the controller not being able to completely understand what the pilot was attempting to say. Rarely did the controllers express difficulty understanding an English-speaking pilot.

Taken together, the results suggest that being able to speak English may be necessary but is not sufficient in limiting communication problems. The proficiency of the speaker in the production of English beyond the minimum specified in the ICAO language proficiency scales must be realized if communication problems are to decline.

Pilot English Language Proficiency and the Prevalence of Communication Problems at Five U.S. Air Route Traffic Control Centers

Approach: "Cessna One Two Three X-ray Yankee, traffic is at your 12 o'clock, 5 miles and 3000 feet, a Saab 340."

Cessna 123XY: "Looking. Where is he? Over the river?"

Approach: "Traffic no factor. He's over the river, through the woods, and on his way to grandmother's house. Contact tower now on 120.7."

— ATC communication

Most residents in the United States recognize "… over the river, through the woods…" as part of the popular song often learned in elementary school during the Thanksgiving season. It is an excerpt from "A Boy's Thanksgiving Day," a poem written by Lydia Maria Child in *Flowers for Children*, volume 2, in 1844. To understand the approach controller's humor requires more than a literal interpretation of the words; it requires an understanding of both U.S. culture and history, and competency in general English. As Walcott (2006) points out, "It is not enough to simply have knowledge: one needs to understand what one knows and be able to communicate it. This ability to communicate what one knows is what determines 'competence.'" This applies equally to pilots and air traffic controllers. For a pilot to successfully communicate with air traffic control requires more than the ability to parrot back the information transmitted by that controller; it requires competency in the language of aviation.

Non-native English-speaking pilots are at a disadvantage flying into countries where their primary or native language is not spoken.[1] Not only must they be able to understand spoken English, the language of aviation, but also speak it when communicating with air traffic controllers whose primary or native language may or may not be English. Historically, some non-native English-speaking pilots had a limited ability to communicate with controllers, and that led some non-English-speaking commercial airlines to include an interpreter as part of the flight crew who could communicate directly with air traffic control (ATC) should the need arise.[2] In other cases, they hired native English-speaking pilots who could no longer fly commercially for U.S. airlines because they were 60 yrs old (Age 60 Rulemaking Committee, 2006; currently § 121.383(c) of Title 14, Code of Federal Regulations [14 CFR]).

Another disadvantage for non-native English-speaking pilots is the disparities between the phraseology adopted by a particular International Civil Aviation Organization (ICAO) member state and the standard phraseology supported by ICAO. For example, the ICAO standard phraseology for an aircraft that is instructed to wait before entering its departure runway is "line up and wait." However, U.S. air traffic controllers use the phraseology "taxi into position and hold." This phraseology may not be familiar to foreign pilots departing from U.S. airports.

Other examples are given in Appendix 1 of the United Kingdom's (U.K.'s) Civil Aviation Authority publication *CAP413 Radiotelephony Manual* (CAA, May 2006). The manual provides a table that details the differences in ICAO and U.K. radiotelephony procedures and phraseology. Presented in Table 1 is an excerpt from that table. The first column illustrates two examples of the differences between the phraseologies, and the second column provides the reason for U.K. noncompliance with ICAO.

In response to a U.S. Congressional request put forth by Representative Bob Franks in 2000, U.S. Inspector General Kenneth Mead undertook an investigation to determine the prevalence of international pilots flying in U.S. airspace who are unable to communicate with air traffic controllers due to inadequate knowledge of the English language and its impact on safety. The findings contained in this response noted that from January 1997 to August 2000, the FAA recorded a total of 16 (out of 309, approximately 5%) pilot deviations[3] nationwide that were attributable to language or phraseology problems between pilots and air traffic controllers.

[1] It may be that the official language of the country is English but the primary language spoken by the pilot is not.

[2] This piece of information was shared with the first author by controllers during informal conversations and confirmed by communications between the first author and some foreign pilots.

[3] FAA Order 7210.56C *Air Traffic Quality Assurance* §4-1-1. Definitions a (3) Pilot Deviation. "the (sic) actions of a pilot that result in the violation of a Federal Aviation Regulation or North American Aerospace Defense (Command Air Defense Identification Zone) Tolerance."

Table 1. Examples of U.K. Differences to ICAO Radiotelephony Procedures.

Details of ICAO/U.K. Difference	Reason/Remarks
Phraseology FLIGHT LEVEL ONE ZERO ZERO (ICAO) is not used in U.K. In the U.K., flight levels ending in hundreds are transmitted as HUNDRED, e.g., FLIGHT LEVEL ONE HUNDRED.	To avoid potential confusion with adjacent flight levels and misidentification of cleared levels, e.g., Flight Level One Zero Zero with FLIGHT LEVEL ONE ONE ZERO.
Phraseology CLEARED FOR ILS APPROACH is not routinely used in the U.K. In the U.K., pilots will be asked to "Report established" on the localizer. Once established, they will then be given clearance to "descend on the ILS." In busy RTF environments, the phraseology may be combined to "When established on the localiser, descend on the ILS..."	Due to procedure design and airspace complexity, along with lessons learned from flight safety related incidents and occurrences, the UK has elected to enhance safety by adopting unambiguous phraseology that includes a positive descent instruction to ensure that descent is initiated only when it is safe to do so.

In 2004, ICAO, an agency of the United Nations, published its *Manual on the Implementation of ICAO Language Proficiency Requirements* in response to several accidents[4] and incidents where language proficiency was cited as either causal or contributing factors. In that same year, the APANPIRG ATM/AIS/SAR Sub-Group[5] (ATM/AIS/SAR/SG/14) presented the Secretariat of ICAO with a document entitled *Language Proficiency* that stipulated "… pilots on international flights shall demonstrate language proficiency in either English or the language used by the station on the ground. Controllers working international services shall demonstrate language proficiency in English as well as in any other language(s) used by the station on the ground." (Para 2.4). Likewise, pilots are governed by Annex 10 ICAO, which establishes the rules of communication between pilots and controllers that are not conversant in each other's native language. Specifically, § 1.2 of Annex 10 states:

"The primary means for exchanging information in air-ground communications is the language of the ground stations, which will in most cases be the national language of the State responsible for the station." Paragraph 5.2.1.1 2 recommends "that where English is not the language of the ground station, the English language should be available on request, thereby, the recommendations of the Annex indicate that the English language will be available as a universal medium for radiotelephone communications."

In March 2008, ICAO implemented its language proficiency requirements.[6] Specifically, "Aeroplane and helicopter pilots and those flight navigators who are required to use the radio aboard an air carrier shall demonstrate the ability to speak and understand the language used for radiotelephony communications."[7] Likewise, "Air traffic controllers and aeronautical station operators shall demonstrate the ability to speak and understand the language used for radiotelephony communications."[8] To retain their licenses, pilots, navigators, controllers, and station operators must meet the language proficiency requirements found in *Manual on the Implementation of ICAO Language Proficiency Requirements* (2004).

There are six levels of operational proficiency ranging from pre-elementary (Operational Level 1) through expert (Operational Level 6). There are six dimensions of proficiency that are evaluated: Pronunciation, Structure, Vocabulary, Fluency, Comprehension, and Interactions. Failure to reach Operational Level 6 language proficiency will require retesting at least once every three yrs if the test results place the pilot at Operational Level 4 or every six yrs if the pilot is at Operational Level 5. The time interval for retesting is determined by the interviewee's demonstrated ICAO operational level of language proficiency in both speaking and understanding.

[4] As an example, in 1990, Avianca Flight 52 was making its third approach into JFK Airport and failed to inform air traffic control they had a fuel emergency and crashed.

[5] Air Traffic Management/Aeronautical Information Services and Search and Rescue (ATM/AIS/SAR) Sub-Group of APANPIRG (Asia Pacific Air Navigation Planning and Implementation Regional Group)

[6] Since the publication of *Appendix A, Manual on the Implementation of ICAO Language Proficiency Requirements*, a draft resolution was put forth that modifies the implementation date (see *Language Proficiency Requirements Resolution A36/11 ICAO TE/36 10/9/07*).

[7] *Appendix A, Manual on the Implementation of ICAO Language Proficiency Requirements.*

8 *Appendix A, Manual on the Implementation of ICAO Language Proficiency Requirements.*

It should come as no surprise that many commercial educational suppliers are rapidly developing instructional and testing materials for the aviation industry to meet the March 2008 timeline. Likewise, many ICAO member states are busily establishing standards by which those instructional and testing materials will be evaluated. What is absent are data from which the effectiveness of those training programs can be assessed. That is, a need exists to describe, baseline, and document current operational communications prior to the implementation of ICAO language proficiency requirements so future research will be able to track whether these requirements actually help to reduce the production of communication problems.

Within the U.S., data are lacking concerning the prevalence of ATC communication problems attributable to the production and comprehension of English. As used in this report, a *communication problem* is a situation in which a message is not understandable in content, speech (accent), structure, accuracy of readback, or any combination of these elements that reaches the level of possibly interfering with ATC procedures. Communication problems are presented involving readback errors (RBEs), breakdowns in communication (BIC), and requests for repetition (RfR) by commercial airline pilots. We have encoded BICs that resulted in interference with ATC procedures, required plain language to resolve, required assistance from other pilots or ATC to convey the message, or in which the SMEs believed that communication had broken down. Unlike RBEs that can be easily determined by comparing the pilot's readback with the controller's message in a couplet or determining the presences of an RfR, BICs often involve multiple transmissions between the controller and pilot in a transaction. Also, there may be several BICs in a transaction. Consequently, there may not be a 1:1 relationship between the controller-pilot exchange of information. The controller-pilot communication process is not a casual, informal vehicle to exchange information — the information in a message carries weight of importance, i.e., **safety**. A communication problem may create an ATC problem.

Therefore, the purpose of this report is to document problematic communications according to the type of aircraft (U.S., foreign), type of communication problem, and frequency of occurrence. Approximately 50 hours of digital audio tapes (DATs) of pilot-controller voice communications were transcribed verbatim and examined for the presence of communication problems. The DATs were requested from five Air Route Traffic Control Centers (ARTCCs). Facility representatives selected sectors and time samples that reflected the busiest international traffic periods.

METHOD

Subject Matter Experts (SMEs)

The first author of this report had 12 yrs of experience analyzing pilot controller communications. The second author was an instrument-rated pilot and former controller who had worked as an FAA Academy instructor for 8 yrs and had worked for 12 yrs in FAA supervision and management. The third author had assisted the second author in encoding pilot-controller communications for more than 10 yrs.

Materials

Audio Tapes. Five ARTCCs were asked to provide 10 hours of voice communications for a total of 51 hours of recordings. Facility representatives identified the sectors and time samples with the heaviest concentration of international traffic. The communications occurred between March and August 2006. Digital autio tape (DAT) recordings were made at each facility using the NiceLogger™ Digital Voice Recorder System (DVRS) to record and timestamp each transmission. Each DAT contained separate voice records of all communication transmitted on the radio frequency assigned to a particular sector position on the left channel. The right channel contained the Universal Time Coordinated (UTC) time code expressed in date, hour (hr), minute (min), and whole second (s). The DVRS decoded and displayed time and correlated it with the voice stream in real time.

A Guide to the Classification of Pilot Readback Errors. As used here, a readback error is defined as an unsuccessful attempt by a pilot to read back correctly the information contained in the communication elements that comprise the original message transmitted by air traffic control. Many of the readback error types are common to all aviation topics (AT).[9] The more typical ones include substitution, transposition, and omission errors. Some types of readback errors may pose a greater risk to safety than others. For example, transposing a number in an AT may be more of a threat in some situations than the omission of a number or the substitution of an anchor word with its synonym.

As seen in Table 2, the column to the right displays the various types of readback errors associated with an altitude. For example, ATC might transmit the following message to AAL10: "AMERICAN TEN TURN LEFT HEADING TWO ONE ZERO." If the pilot reads back either "THREE ONE ZERO" or "SIX ZERO," it would be coded as a substitution error since the numbers in the original heading instruction included neither a three nor a six. The complete *Readback Error Guide* appears in Appendix A.

[9] An aviation topic refers to the type if information in an ATC message (e.g., heading, speed, altitude, runway, etc.).

Table 2. An Example From the Readback Error Guide.

Classification of Readback Errors	Examples
ATC: "AAL Ten climb and maintain one two thousand"	
Readback Errors Type (ALT)	
1 = Substitution of message numbers/flight level vs. thousand	**1-**"maintain one **three** thousand" "maintain **flight level** one two"
2 = Substitution of climb with descend or descend with climb	**2-**"**descend** maintain one two thousand"
3 = Substitution of message numbers with incorrect climb/descend	**3-**"**descend** maintain **one three** thousand"
4 = Transposition of message numbers with incorrect climb/descend	**4-**"**descend** maintain **two one** thousand"
5 = Transposition of message numbers	**5-**"climb maintain **two one** thousand"
6 = One type of information read back as another type of information	**6-**"AAL Ten one two zero **knots**"
7 = Omission of anchor word(s)	**7-**"one two"
8 = Omission of number elements	**8-**"climb maintain"
9 = Omission of anchor word(s) and some number elements	**9-**"climb two thousand"

The ICAO Language Proficiency Rating Scale. The *Manual on the Implementation of ICAO Language Proficiency Requirements* (2004) provides the criteria and rating scales for evaluating ICAO language proficiency. There are six levels of operational proficiency ranging from pre-elementary (Operational Level 1) through expert (Operational Level 6). Six dimensions of proficiency are evaluated. They include Pronunciation (pronunciation, stress, rhythm, and intonation), Structure (grammar, sentence patterns, global-meaning errors, local errors[10]), Vocabulary (style, tone, lexical choices that correspond to context and status, idiomatic expressions, and express subtle differences or distinction in expression, meaning), Fluency (naturalness of speech production, absence of inappropriate hesitations, stammers, or pauses that may interfere with comprehension), Comprehension (clear and accurate information transfer that results in understanding), and Interactions (sensitive to verbal and nonverbal cues and responds to them appropriately). Within the context of voice tape analysis, nonverbal cues would be limited to periods of silence beyond that of normal breathing and the expected periods of brief silence that occur at the end of a phrase, clause, or sentence.

Procedure

Data Transcription. One set of audiocassette tapes was dubbed from each digital audio tape and provided to the transcribers, who used them to generate the verbatim transcripts. Each transmission was associated with the originating facility, sector, date, and transmission number. Aircraft call signs (i.e., the company name and flight number) were used to group transmissions by air carrier registry (U.S., Foreign) and language (English, Other). *FAA Order JO 7340.1Z Contractions* (FAA 2007) was used as a reference in the classification process. Each message was preceded by its onset and offset time represented in hour (hr) minute (min) and second (s) after it was typed onto an electronic copy of the Aviation Topics Speech Acts Taxonomy-Coding Form (ATSAT-CF; Prinzo, Britton, & Hendrix, 1995).

Once the transcribers finished a set of tapes for an ARTCC, the second and third authors were provided with copies of the transcripts, video maps, procedures manual, air carrier identifiers, and other materials that they requested for use during the encoding process. They also were provided with a DVRS and the facility-provided DATs were loaded onto it to facilitate message encoding. This process was followed for each of the five ARTCCs.

[10] In linguistics, global errors typically occur between independent and dependent clauses in a sentence that can result in confusion. Local errors occur within a clause and may involve article usage, verb tense, etc.

Table 3. Parsed ATC Message Categorized by Speech Acts and Aviation Topics.

SPKR	Message	T1	T2	T3	T4
ATC	OWNSHIP SIXTY FOUR TEN/ {FID} / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL TWO THREE ZERO*	RID	SID	IS	IA

Table 4. ATC Message Couplets.

SPKR	Message	T1	T2	T3	T4
ATC	OWNSHIP SIXTY FOUR TEN/ {FID} / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL TWO THREE ZERO*	RID	SID	IS	IA
FD6410	OKAY / NORMAL SPEED /AND UP TO *FLIGHT LEVEL TWO FOUR ZERO* /OWNSHIP SIXTY FOUR TEN	IGA	IS	IA	SID

Table 5. Identification of Communication Problems.

SPKR	Message	Com Prob	Type Prob	Type RBE	RBE AT
ATC	OWNSHIP SIXTY FOUR TEN/ {FID} / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL* ***TWO THREE ZERO***	1	1	1	IA
FD6410	OKAY / NORMAL SPEED /AND UP TO *FLIGHT LEVEL* ***TWO FOUR ZERO*** /OWNSHIP SIXTY FOUR TEN	1	1	1	IA

Message Encoding. Message encoding was a 4-stage process. It began with the receipt of a complete set of transcripts, audio media of the communications, and reference materials.

Step 1. In Step 1, each controller message was parsed into communication elements and categorized by speech act and aviation topic using the protocol established by Prinzo, Hendrix, and Hendrix (2007). In Table 3, the column labeled "T1" is the receiver identification, under "T2" is the speaker identification (in the example, FID stands for Facility Identification and it refers to the name of the ARTCC), "T3" contains a speed instruction (IS), and "T4" shows that the last communication element is an instruction to change altitude (IA). The transmission contained four communication elements, of which two involved instructions and two identified the speaker (SID) and receiver (RID) of the transmission.

Step 2. In Step 2, each controller transmission was paired with the pilot's reply to that message. The aircraft identifier and message contents were used to match the controller's transmission with the pilot's response. As shown in Table 4, the controller transmitted a message to the flight deck (FD) of Ownship 6410, to which the pilot replied with a general acknowledgment, the readback of the speed and altitude instructions, followed by the air carrier's call sign.

Step 3. In Step 3, each readback was evaluated for accuracy. This is a multistage encoding process. As shown in Table 5, if no problem was present, then a "0" was entered under the column labeled "Com Prob." Otherwise, the number of communication problems was recorded for the entire message. In this example, there was one identified communication problem in the couplet, so the value of "1" appears in that column.

Then the type of communication problem was coded under the column labeled "Type Prob." Communication problems were coded as readback error (RBE) = 1, breakdown in communication (BIC) = 2, and request for repeat (RfR) = 3. If a communication problem was identified that did not match the pre-defined classifications, then it was assigned a new value and added to the classification scheme. Presented below is an example of each type of communication problem. The information within a message appearing in bold font serves to isolate the problematic aspects of the transmission or transaction.

Encoding Readback Errors. As shown in Table 5, there is an error involving the readback of the altitude instruction. Using the *Guide to the Classification of Pilot Readback Errors* (Appendix A), the readback errors were grouped according to their type (e.g., substitution = 1, transposition = 2, omission = 3, combination = 4). In Transmission 1, the controller instructed the pilot to "CLIMB MAINTAIN FLIGHT LEVEL TWO THREE ZERO." In

Table 6. An Example of a Breakdown in Communication.

SPKR	Tx	Message	Com Prob	Type Prob
ATC	1	OWNSHIP SIX / **TURN FIFTEEN DEGREES RIGHT** VECTOR FOR TRAFFIC	1	2
FD6	2	A **RIGHT / TURN TEN DEGREE** OWNSHIP SIX	1	2
ATC	3	OWNSHIP **TURN FIFTEEN DEGREES RIGHT** VECTOR FOR TRAFFIC / EXPECT DIRECT {INTERSECTION} IN TWO ZERO MILES	0	0
FD6	4	OWNSHIP SIX / **ROGER**	0	0
ATC	5	OWNSHIP SIX / YOUR READBACK WAS UH BROKEN / **TURN FIFTEEN DEGREES RIGHT**	1	2
FD6	6	**TURN TEN DEGREES TO THE RIGHT**	1	2
ATC	7	OKAY / **TEN DEGREES RIGHT** / OWNSHIP SIX	0	
FD6	8	OWNSHIP SIX / ON HEADING ONE FOUR FIVE	0	

Transmission 2, the pilot erroneously read back "FLIGHT LEVEL TWO **FOUR** ZERO." The readback error was classified as a substitution error since none of the numbers in the original altitude instruction contained the number 4.

The last part of the identification of readback errors defined which of the aviation topics were read back incorrectly. Since the faulty readback involved the altitude instruction, "IA" was coded under the column labeled "RBE AT."

Encoding Breakdowns in Communication. Pivotal to a breakdown in communication is a failure between the controller and pilot to achieve a mutual understanding, which can result in interference with ATC procedures. A BIC often involves multiple transmissions before the problem is resolved.

Presented in Table 6 is an example of a BIC. It begins in Transmission 1 with the controller instructing the pilot to change the aircraft's heading by 15 degrees. In Transmission 2, the pilot reads back a heading change of 10 degrees. We would have encoded that message couplet as a readback error, except that the controller repeated the same instruction in Transmission 3, to which the pilot replied "ROGER" in Transmission 4. In Transmission 5, the controller rightfully restates the same instruction a third time because the acknowledgment "ROGER" does not ensure that the pilot understood that the controller wanted a 15-degree turn to the right, especially when the preceding readback was incorrect. In Transmission 6, the pilot yet again provides the same erroneous readback. Apparently, the controller realizes (through inference) that the pilot wants a 10-degree, not a 15-degree, change in heading. In Transmission 7, the controller issues the instruction to change heading by turning 10 degrees to the right. In the final transmission, the pilot reads back the new heading. This is a classic example of a "failure to communicate." It would have been much more effective for the pilot to request a different heading rather than wear the controller down and possibly create an unsafe situation, especially when the course change is due to traffic. Thus, this transaction was encoded as a BIC involving an instruction to change heading.

Encoding Requests for Repeat. There are key words that signal that a pilot needs to have information contained in a previous ATC transmission given a second time. Some of these anchor words are "SAY AGAIN," "CONFIRM," "VERIFY," "COULD YOU REPEAT," etc. In some cases, the pilot only needs some of the information restated, whereas in others the request may be for the all the information contained in the ATC transmission. We identified four different types of requests: (1) confirmation/verification of a specific AT; (2) confirmation that the transmission was for them; (3) requests for the repetition of a specific AT; and (4) repetition of an entire transmission. Presented in Table 7 is an example of a pilot request to have the entire ATC transmission repeated.

As shown in Table 7, in Transmission 2, the pilot correctly read back the information contained in the controller's first transmission. However, in Transmission 3, the pilot asks the controller to repeat the entire transmission a second time. In Transmission 4, the controller complies with the pilot's request but changes the previously issued altitude of one seven thousand to flight level one niner zero. We do not know why the controller changed the altitude. Transmissions 3, 4, and five are encoded as containing a communication problem involving an RfR.

Step 4. In Step 4, the *ICAO Language Proficiency Rating Scale* guided the encoding of English Language Proficiency (ELP). To aid encoding the language proficiency, the encoder had a copy of the transcript to read while listening to the digitized audio transmissions and a copy of the *ICAO Language Proficiency Rating Scale*. The encoder listened to a transmission multiple times while assigning a value along each dimension. No attempt was

Table 7. An Example of a Request for Repeat.

SPKR	Tx	Message	Com Prob	Type Prob	Type RfR
ATC	1	OWNSHIP TWENTY TWO SEVENTY SIX / AMEND ALTITUDE MAINTAIN ONE SEVEN THOUSAND / CLEARED DIRECT TO {FIX}	0	0	0
FD2276	2	ONE SEVEN THOUSAND / UH DIRECT {FIX} / OWNSHIP TWENTY TWO SEVENTY SIX	0	0	0
FD2276	3	{FID} / **COULD YOU REPEAT** / FOR OWNSHIP TWENTY TWO SEVENTY SIX / SORRY	1	3	4
ATC	4	OWNSHIP TWENTY TWO SEVENTY SIX / CLEARED DIRECT TO {FIX} / CLIMB MAINTAIN FLIGHT LEVEL ONE NINER ZERO NOW	1	3	4
FD2276	5	ALRIGHT / FLIGHT LEVEL ONE NINE ZERO / DIRECT {FIX} OWNSHIP TWENTY TWO SEVENTY SIX / THANK YOU	1	3	4

made to classify a speaker's utterance according to ICAO's six Operational Levels of ELP. However, Pronunciation, Structure, Vocabulary, Fluency, Comprehension, and Interactions were scored as either 0 = not a problem, or 1 = was a problem for the transmission, using the descriptors provided on the *ICAO Language Proficiency Rating Scale*.

Presented in Table 8 are the same examples presented in Tables 5, 6, and 7, along with the ratings of "0" or "1" for each message on the six dimensions of ELP. The transaction with the RBE was found not to contain any ELP problems. Had the "UH" in Transmission 3 appeared embedded within the aviation topic rather than preceding it, a possible fluency problem would be noted with a "1" in its designated column. The transaction with a BIC had problems associated with pronunciation (pilot flew a Foreign-Other aircraft and the accent affected the intelligibility of the utterance) and possibly comprehension. In two instances, the pilot's readback was incorrect and in a third, the pilot replied "ROGER," which implies understanding. All three pilot replies were to the same heading instruction. In the RfR example, there is one instance of a potential fluency problem (the pilot's words run together).

Encoding Reliability. Inter-rater reliability was evaluated by having the first and second author randomly encode the same set of 125 messages (25 for each facility). Since the first and second author both used *A Guide to the Computation of Level of Complexity* to compute complexity, it was expected that there would be a high percentage of agreement between them. Krippendorff's alpha (α),[11] a reliability coefficient was performed on their ratings as each set of data was completed and after all the data were encoded. Treating the ratings as ordinal data produced $\alpha = .945$, indicating high inter-coder agreement.

RESULTS

Only transactions between controllers and pilots who flew for commercial air carriers were analyzed. The transactions began with the aircraft checking in, involved changes in trajectories, speeds, altitudes, runway assignments, other aviation topics, and ended with a transfer of communications (TOC). There were 4,816 pilot transmissions (78% English, 22% Other) from 832 aircraft (74% U.S., 26% Foreign) that were aggregated according to facility, sector, time sample, and flight identifier (the company name coupled with its flight number). They represented 53 different U.S. air carriers, U.S.-English (e.g., American, Continental, Delta, United, etc.), ten foreign air carriers with English as their primary or official language, Foreign-English (e.g., Speedbird, Tradewinds, New Zealand, Qantas, etc.), 52 foreign air carriers with a language other than English as their primary or official language, Foreign-Other (e.g., Air France, Mexicana, Pakistan, Swiss). Consequently, flight identifier and language was combined to create one factor with three groups: Registry-Language (U.S.-English n = 642; Foreign-English n = 26; Foreign-Other n = 164).

Three sets of analyses were performed. The first set examined the mean total radio frequency occupancy, mean number of transmissions, and mean total number of communication problems in a transaction. Of these 832 transactions, 23% contained one or more communication problems (U.S.-English = 21%, Foreign-English = 19%, Foreign-Other = 30%). The second set was restricted to

[11] Krippendorff's alpha is a reliability coefficient that was originally developed for evaluating agreement between coders performing a content analysis. It is a statistic that is widely applicable wherever 2 or more methods of processing data are applied to the same set of objects, units of analysis, or items and the question is how much they agree (Krippendorff, 1980).

Table 8. Encoding of ATC/FD Messages According to ICAO ELP Dimensions.

SPKR	Types of Communication Problems	ICAO ELP Dimensions					
		Pronunciation	Structure	Vocabulary	Fluency	Comprehension	Interaction
	READBACK ERROR (RBE)						
ATC	OWNSHIP SIXTY FOUR TEN RESUME NORMAL SPEED CLIMB MAINTAIN **FLIGHT LEVEL TWO THREE ZERO**	0	0	0	0	0	0
FD6410	OKAY NORMAL SPEED AND UP TO **FLIGHT LEVEL TWO FOUR ZERO** OWNSHIP SIXTY FOUR TEN	0	0	0	0	0	0
ATC	SKYWEST SIXTY FOUR TEN **NEGATIVE IT'S FLIGHT LEVEL TWO THREE ZERO**	0	0	0	0	0	0
FD6410	OKAY I'LL TURN UP THE HEARING AID UH **FLIGHT LEVEL TWO THREE ZERO** SKYWEST SIXTY FOUR TEN	0	0	0	0	0	0
	BREAKDOWN IN COMMUNICATIONS (BIC)						
ATC	OWNSHIP SIX **TURN FIFTEEN DEGREES RIGHT** VECTOR FOR TRAFFIC	0	0	0	0	0	0
FD6	A **RIGHT TURN TEN DEGREE** OWNSHIP SIX	1	0	0	0	1	0
ATC	OWNSHIP **TURN FIFTEEN DEGREES RIGHT** VECTOR FOR TRAFFIC EXPECT DIRECT {INTERSECTION} IN TWO ZERO MILES	0	0	0	0	0	0
FD6	OWNSHIP SIX **ROGER**	1	0	0	0	0	0
ATC	OWNSHIP SIX YOUR READBACK WAS UH BROKEN **TURN FIFTEEN DEGREES RIGHT**	0	0	0	1	0	0
FD6	**TURN TEN DEGREES TO THE RIGHT**	1	0	0	0	1	0
ATC	OKAY **TEN DEGREES RIGHT** OWNSHIP SIX	0	0	0	0	0	0
FD6	OWNSHIP SIX ON HEADING ONE FOUR FIVE	1	0	0	0	0	0
	REQUEST for REPEAT (RfR)						
ATC	**OWNSHIP TWENTY TWO SEVENTY SIX AMEND ALTITUDE MAINTAIN ONE SEVEN THOUSAND CLEARED DIRECT TO {FIX}**	0	0	0	0	0	0
FD2276	ONE SEVEN THOUSAND UH DIRECT {FIX} OWNSHIP TWENTY TWO SEVENTY SIX	0	0	0	0	0	0
FD2276	{FID} **COULD YOU REPEAT** FOR OWNSHIP TWENTY TWO SEVENTY SIX SORRY	0	0	0	1	0	0
ATC	**OWNSHIP TWENTY TWO SEVENTY SIX CLEARED DIRECT TO {FIX} CLIMB MAINTAIN FLIGHT LEVEL ONE NINER ZERO NOW**	0	0	0	0	0	0
FD2276	ALRIGHT FLIGHT LEVEL ONE NINE ZERO DIRECT {FIX} OWNSHIP TWENTY TWO SEVENTY SIX THANK YOU	0	0	0	0	0	0

Table 9. Transaction Throughput Presented by Aircraft Registry-Language.

Aircraft Registry-Language	Total Frequency Occupancy Time (sec)	Total Pilot Transmissions	Mean Number of Communication Problems
Foreign-English	19.27 (11.35)	6.81 (3.25)	.19 (0.40)
Foreign-Other	19.75 (13.17)	6.46 (3.02)	.51 (1.08)
U.S.-English	13.61 (7.87)	5.57 (2.71)	.30 (0.71)

examine the content of the pilot-controller communications that had one or more communication problems. It was conducted on 1,532 pilot transmissions, representing 204 flights. The third set attempted to classify the transactions with communication problems using the ICAO language proficiency scales (but not assigning operational levels of proficiency). For that analysis, 348 pilot transmissions were analyzed. For all analyses, statistical significance was set at $p \leq .05$.

Analysis One: Transaction Throughput

The English language proficiency of individual pilots and controllers will be considered in a future report. In that report, the operational level of the ICAO scales will be applied to each utterance in a transaction with one or more communication problem for each Registry-Language aircraft.

There were three dependent measures that comprised transaction throughput: the total amount of time the pilot of an aircraft was on the radio frequency communicating with the controller (Total Frequency Occupancy Time reported in seconds), the total number of pilot transmissions, and the total number of communication problems in the transaction (Mean Number of Communication Problems). All the means and standard deviations (presented in parentheses) for the throughput measures are presented in Table 9.

A Multivariate Analysis of Variance (MANOVA), conducted to determine whether or not Registry-Language resulted in differences in transaction throughput, was statistically significant [$F(6,1654) = 12.83$]. Subsequently, Univariate ANOVA procedures were used to evaluate the effects of Registry-Language on each dependent measure, and Fisher's Least Significant Difference (LSD) statistic isolated statistically significant differences between the three groups for each dependent measure. All Registry-Language of the ANOVAs were statistically significant. The results are discussed below. The complete table of results appears in Appendix B.

Frequency Occupancy Time. The Registry-Language ANOVA was statistically significant [$F(2,829) = 31.51$]. Post hoc comparisons revealed that the pilots flying foreign registry aircraft spent 6 sec more on frequency speaking with controllers than pilots flying for a U.S. air carrier and no difference due to language among the pilots flying a foreign air carrier.

Total Pilot Transmissions per Transaction. The Registry-Language ANOVA revealed that the pilots flying foreign registry aircraft transmitted more messages to ATC than the pilots of U.S. registry aircraft [$F(2,829) = 8.42$]. Furthermore, post hoc comparisons showed no statistical difference due to language (English, Other) among the foreign aircraft.

Mean Total Number of Communication Problems. The results indicate that when air carriers had a language other than English as their primary or official language, the communications of their pilots with controllers resulted in more communication problems per transaction [$F(2,829) = 5.23$]. Post hoc comparisons revealed no reliable difference between U.S. and foreign registry flights when the primary language of the aircraft was English.

Analysis Two: Types of Communication Problems

For the second set of analyses, the chi-square statistic was used to examine the influence of Registry-Language on the prevalence of communication problems in the en route environment. The Foreign-English registry aircraft were excluded because they did not fulfill the requirements of the chi-square statistic (Registry and Language were not mutually exclusive). Furthermore, only the transmissions with one communication problem underwent the chi-square analysis. Statistical significance was set at $p \leq .05$. The findings revealed that there was a difference in the number of communication problems experienced by pilots who flew Foreign-Other as compared with U.S.-English registered aircraft, [$X^2(2) = 20.50$].

Table 10. Communications Problems Presented by Aircraft Registry-Language.

Aircraft Registry-Language	Type of Communication Problem						Total
	One Problem			Two or More Problems			
	RBE	RfR	BIC	RBE + RfR	RBE + BIC	RfR + BIC	
Foreign-English	1	4	0	0	0	0	5
Foreign-Other	**18**	**48**	**11***	1	2	4	84
U.S.-English	**97**	**64**	**29**	0	1	1	192
Total	116	116	40	1	3	5	281

** Bold values included in chi-square analysis.*

A content analysis was performed on the communication problems to determine which aviation topics were problematic for the pilots. This was done for each type of communication problem according to Registry-Language, and their types and frequency of communications problems are presented for all three groups in Table 10.

The data for Foreign-Other registry aircraft presented in Table 10 show that for transactions with *one* communication problem, 23% (18/77) of the communication problems were readback errors, 62% were requests for repeat, and 14% involved breakdowns in communication. Approximately 51% (97/190) of the U.S.-English registry aircraft transmissions with *one* communication problem involved readback errors (RBE), 34% requests for repeat (RfR), and 15% breakdowns in communication (BIC). There were only five communication problems involving Foreign-English registry aircraft. Of the nine transmissions with multiple problems, eight involved a breakdown in communications — six with Foreign-Other registry aircraft and two with U.S.-English registry aircraft.

Readback Errors. Since there was only one RBE (an altitude restriction) made by a Foreign-English aircraft, it was not included in Figure 1. Consequently, only the readback errors made by Foreign-Other and U.S.-English registry aircraft were categorized by type of aviation topic. As shown in Figure 1, the read back of radio frequency aviation topics accounted for 24% of readback errors among pilots flying Foreign-Other registry aircraft and nearly 31% of readback errors among pilots flying U.S.-English registry aircraft. For pilots flying Foreign-Other registry aircraft, 20% of their readback errors were attributed to altitude and altitude restrictions, as compared with 31% by pilots flying U.S.-English registry aircraft. Strikingly, route clearances accounted for about 19% of the readback errors made by pilots flying Foreign-Other registry aircraft, compared with only 2% for U.S.-English registry aircraft.

Requests for Repeat. The types of RfR transmissions are presented by Registry-Language in Table 11. There are four types: (1) 46% involved the confirmation of a specific AT (e.g., CONFIRM THAT WAS TWENTY EIGHT POINT ONE FIVE); (2) 16% were confirmation that the transmission was for them, (e.g., alright one nine zero that was for ownship thirty one fifty eight); (3) 17% were the repetition

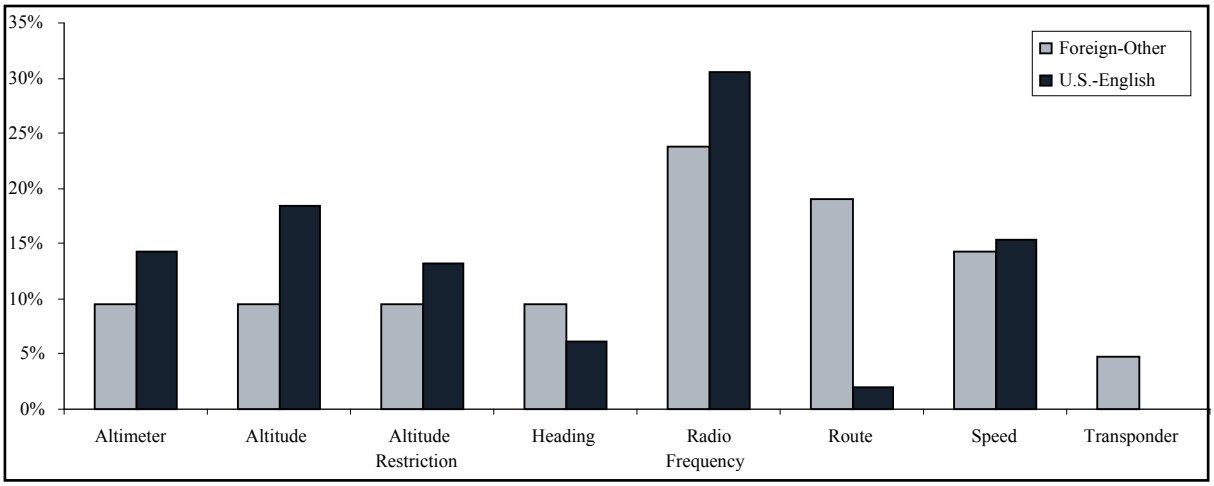

Figure 1. Readback Errors Presented by Aviation Topic and Aircraft Registry.

Table 11. Requests for Repeat Presented by Aircraft Registry-Language.

Aircraft Registry-Language	Confirmation		Say Again		
	Aviation Topic	Was that for me?	Aviation Topic	Transmission	Total
Foreign-English	3	0	1	0	4
Foreign-Other	27	5	8	13	53
U.S.-English	26	14	12	13	65
Total	56	19	21	26	122

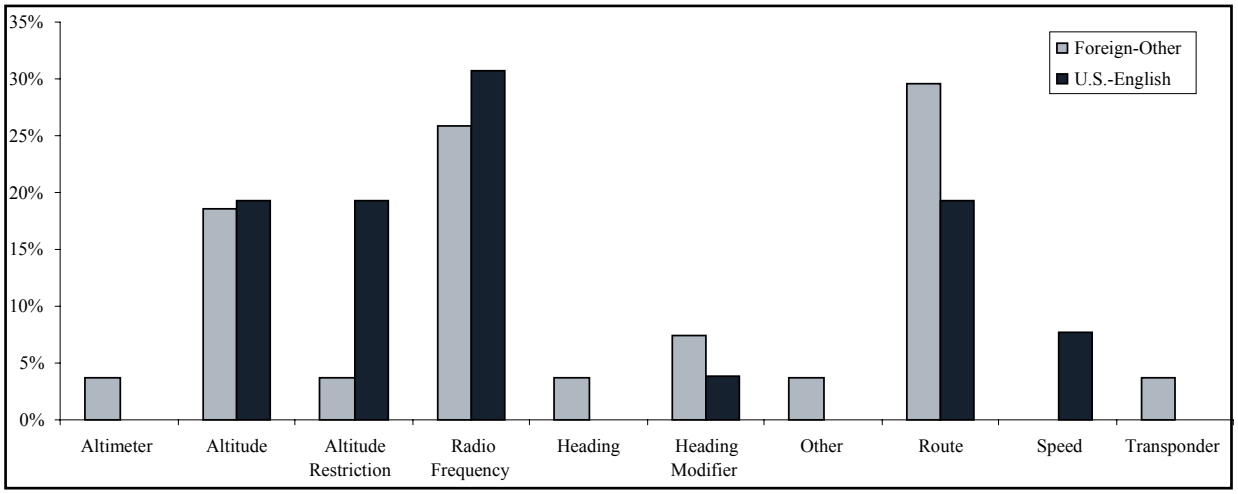

Figure 2. Confirmations Presented by Aviation Topic and Aircraft Registry.

of a specific aviation topic (e.g., SAY AGAIN THE ALTIMETER SETTING PLEASE); and (4) 21% involved the repetition of an entire transmission (e.g., SAY AGAIN PLEASE).

Requests for Confirmation of a Particular Aviation Topic. As seen in Table 11, 50% (27/53) of the Foreign-Other and 40% (26/65) of the U.S.-English flights' RfR involved confirmation of a particular aviation topic. The composition of these requests is presented in Figure 2. It shows that requests to confirm the accuracy of the read back of radio frequencies accounted for 26% of the RfR made by flights operated by Foreign-Other registry aircraft and about 31% by U.S.-English registry aircraft. Confirmation of routes accounted for 30% of the Foreign-Other flights and 19% of the U.S.-English flights. When altitude and altitude restriction instructions were combined, they jointly accounted for 23% of the Foreign-Other and 38% of the U.S.-English confirmations of a particular aviation topic.

Requests for Repeat of a Particular Aviation Topic (Say Again). There were 20 requests for ATC to repeat a particular aviation topic (40% Foreign-Other, 60% U.S.-English). As shown in Figure 3, of these "say agains," 13% of the Foreign-Other and 25% of the U.S.-English flights RfR involved radio frequencies. Requests of "say again route clearances" involved 63% of the Foreign-Other and 25% of the U.S.-English flights. Another 13% of the Foreign-Other compared with 25% of the U.S.-English flights' "say agains" involved altimeters. Finally, only the pilots of aircraft operated by U.S.-English registry aircraft asked for a repeat of altitude, speed, and transponder aviation topics.

Breakdowns in Communication. There were 467 pilot-controller messages from 26 aircraft (35% Foreign-Other, 65% U.S.-English) that involved 48 BICs. None involved Foreign-English registry aircraft. The types of information that contributed to the problems appear in Figure 4.

Unlike readback errors and requests for repeats, breakdowns in communication are more complex and often involve multiple exchanges between ATC and the flight deck. Although both the Foreign-Other and U.S.-English registry aircraft had a 15% breakdown in communication, there were eight transactions with multiple problems — six with Foreign-Other and two with U.S. registry aircraft. Among the Foreign-Other registry aircraft, 82% of the transmissions involved runway assignments (41%) and route clearances (41%). Approximately 33% of the messages from U.S.-English registry aircraft involved

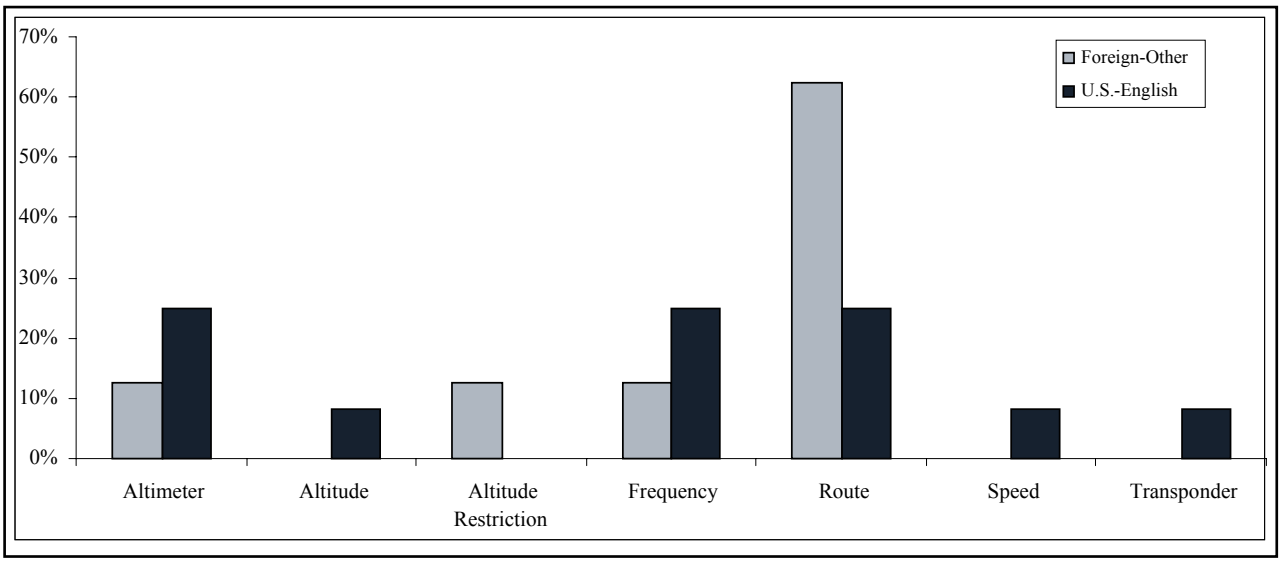

Figure 3. "Say Agains" Presented by Aviation Topic and Aircraft Registry.

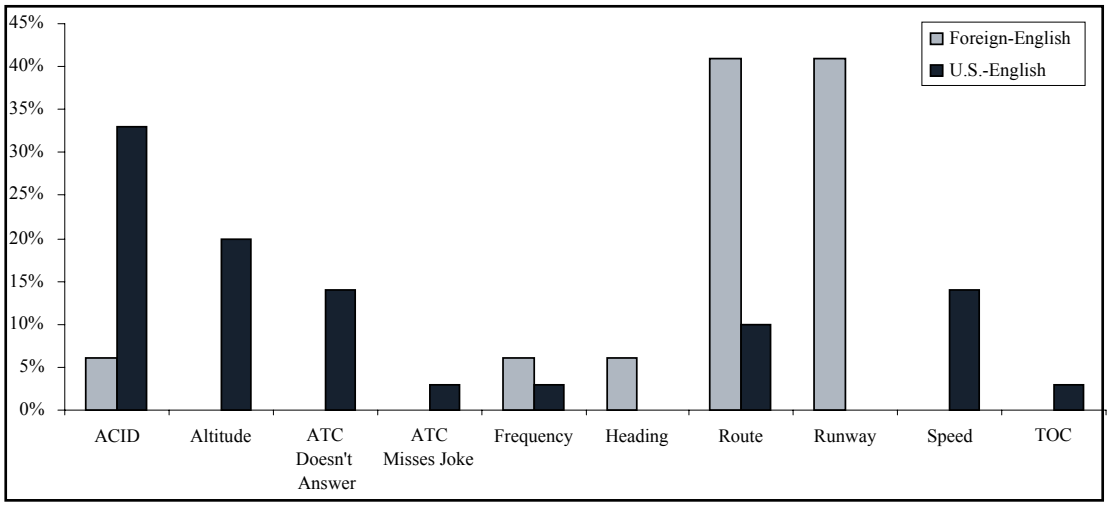

Figure 4. Breakdowns in Communication Presented by Aviation Topic and Aircraft Registry.

incorrect call signs, and 19% were related to the transfer of communication (early transfer of communications, problem with the assigned radio frequency, ATC doesn't answer initial call-up).

Analysis Three: English Language Proficiency and Communication Problems

A Registry-Language by ELP chi-square analysis was performed on the 276 communication problems made by the Foreign-Other and U.S.-English aircraft. Foreign-English registry aircraft were excluded from the chi-square analysis because of their shared classification with aircraft registry and language. As shown in Table 12, ELP was a factor for 75% of the identified communication problems among Foreign-Other flights and for 29% involving U.S.-English flights [X^2 = 50.05].

Each pilot transmission association with a readback error (120), request for repeat (122), and breakdown in communication (106) was examined for any possible problem with English language proficiency. Since readback errors and requests for repeat involve transaction couplets (i.e., ATC sends a message to the flightdeck and the pilot replies), there would be one instance for each pilot reply. However, when a breakdown in communication occurs, there are more transmissions from the flight deck and ATC. There were 31 transactions with 48 embedded breakdowns in communication that involved 106 transmissions from the flight deck.

Table 12. The Influence of Pilot English Language Proficiency on the Production of Communication Problems.

	Was English Language Proficiency a Factor?		
Registry-Language	**No**	**Yes**	**Total**
Foreign-Other	21	63	84
U.S.-English	136	56	192
Total	157	119	276

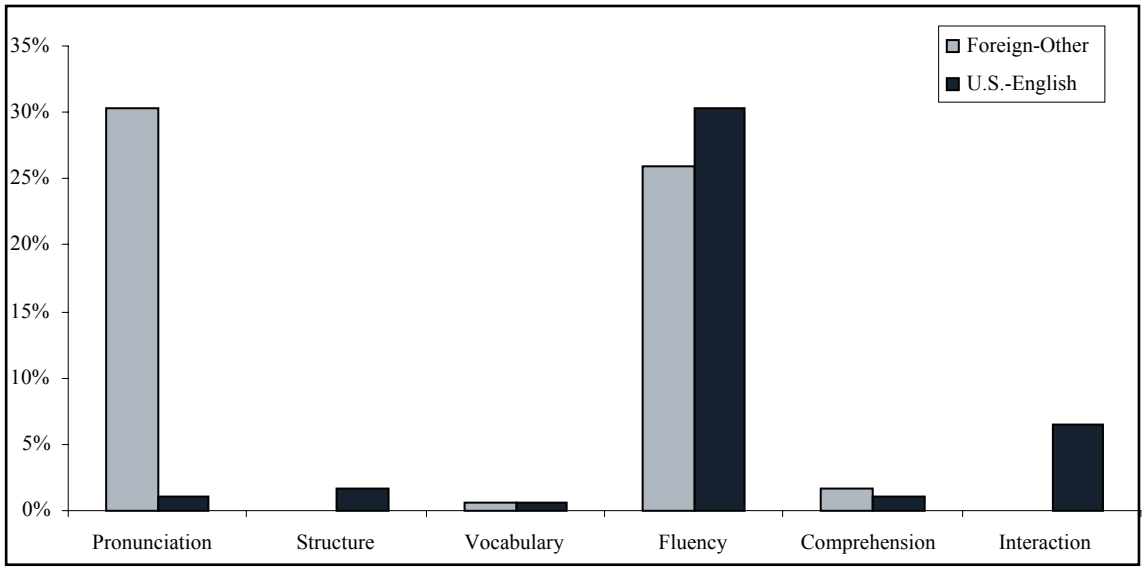

Figure 5. Breakdowns in Communication Presented by ELP Scales and Aircraft Registry.

There were 189 instances of ELP problems that were identified from 348 pilot transmissions (ELP could be a problem across more than one dimension of the ICAO Scales). Since there were only four instances of an ELP problem among the Foreign-English flights (Pronunciation = 1, Structure = 1, Fluency = 2), only the ELP problems associated with the Foreign-Other and U.S.-English flights are presented in Figure 5.

Figure 5 shows that of all the identified communication problems, 30% were associated with pronunciation, 26% with fluency, and 2% comprehension attributed to pilots who flew Foreign-Other registry aircraft. Likewise, for pilots flying U.S.-English registry aircraft, 30% of the remaining ELP problems involved fluency, 6% involved interactions, and 2% structure. A detailed examination of these instances follows according to Registry-Language and types of communication problem.

Table 13. Readback Errors Presented by English Language Proficiency and Aircraft Registry-Language.

English Language Proficiency	Foreign-English	Foreign-Other	U.S.-English	Total
Pronunciation				
All words understood with minimal or no accent	1	10	97	108
Accent required close attention to understand word(s)		7		7
Could not understand all words		2	1	3
Drawn out words/skipped syllables		2		2
Structure				
Message in logical ATC content and order	1	21	96	118
Substitution(s) not consistent with standard phraseology			2	2
Vocabulary				
Appropriate words	1	21	98	120
Non-standard phraseology				
Fluency				
Used words and phrases easily	1	14	83	98
Dysfluency / misarticulation		6	14	20
Words run together		1	1	2
Comprehension				
Message understood	1	20	98	119
Message not understood		1		1
Interaction				
Responded with related message	1	21	98	120
Responded with unrelated message				

Readback Errors and English Language Proficiency. Pilot ELP was examined for 120 transmissions with a readback error according to Registry-Language. As seen in Table 13, pronunciation was a factor for 52% (11/21) of the Foreign-Other registry aircraft RBEs. Upon closer examination, 64% (7/11) of their difficulties with pronunciation were attributed to the pilots' accents; it was difficult for the controllers to understand what was being said. Only 1% (1/98) of the U.S.-English registry aircraft's RBEs resulted from the pilots' either drawing out words or skipping syllables.

There were two instances where U.S. pilots used the wrong structure during their readbacks — In response to the ATC instruction "…CROSS [FIX] AT ONE ZERO THOUSAND [AIRPORT] ALTIMETER THREE TRIPLE ZERO," the pilot read back, "[FIX]ONE ZERO THOUSAND AND THREE TRIPLE ONE OWNSHIP FIVE THIRTY ONE WE'RE AT ABOUT TWO TWENTY KNOTS." Pilot fluency with controllers was a problem in seven of the Foreign-Other and 15 of the U.S.-English flights. Finally, comprehension was a factor in one Foreign-Other transaction.

Table 14. Request for Repeat Presented by English Language Proficiency and Aircraft Registry-Language.

English Language Proficiency	Foreign-English	Foreign-Other	U.S.-English	Total
Pronunciation				
All words understood with minimal or no accent	3	34	65	102
Accent required close attention to understand word(s)		19		19
Could not understand all words	1			1
Drawn out words/skipped syllables				
Structure				
Message in logical ATC content and order	3	52	64	119
Substitutions not consistent with standard phraseology	1	1	1	3
Vocabulary				
Appropriate words	4	53	65	122
Non-standard phraseology				
Fluency				
Used words and phrases easily	2	27	42	71
Dysfluency / misarticulation	2	26	22	50
Words run together			1	1
Comprehension				
Message understood	4	53	65	122
Message not understood				
Interaction				
Responded with related message	4	53	65	122
Responded with unrelated message				

Request for Repeat and English Language Proficiency. Pilot ELP was examined for 122 transmissions with an RfR according to Registry-Language. Notably, Table 14 shows that accent was a factor for 36% (19/53) of the Foreign-Other registry aircraft only. Furthermore, two foreign RfR and one U.S. RfR included the substitution of words/phrases that was inconsistent with standard phraseology. Among the U.S.-English flights, there was one instance in which the pilot's words ran together, making it difficult to understand what was being said and 22 other instances that contained fluency problems. Among the Foreign-Other flights, possible problems with fluency were recorded 26 times. None of the other ELP dimensions were represented in any other RfR.

Breakdowns in Communication and English Language Proficiency. There were 106 pilot transmissions involved in breakdowns in communication. Approximately 38% of the U.S.-English registry aircraft transmissions (28/73) had one or more ELP problems. In contrast, 76% of the transmissions (25/33) by Foreign-Other registry aircraft had one or more problems with ELP. There were no BICs for Foreign-English registry aircraft.

Table 15. Breakdown in Communication Presented by English Language Proficiency and Aircraft Registry-Language.

English Language Proficiency	Foreign-English	Foreign-Other	U.S.-English	Total
Pronunciation				
All words understood with minimal or no accent		7	72	79
Accent required close attention to understand word(s)		17		17
Could not understand all words		9		9
Drawn out words/skipped syllables			1	1
Structure				
Message in logical ATC content and order		33	73	106
Substitutions not consistent with standard phraseology				
Vocabulary				
Appropriate words		32	72	104
Non-standard phraseology		1	1	2
Fluency				
Used words and phrases easily		18	55	73
Dysfluency / misarticulation		15	18	33
Words run together				
Comprehension				
Message understood		31	71	102
Message not understood		2	2	4
Interaction				
Responded with related message		33	61	94
Responded with unrelated message			12	12

As shown in Table 15, among the pilots flying Foreign-Other registry aircraft, accent affected the intelligibility of 79% (26/33) of the messages transmitted to ATC. There was one instance of pilot use of non-standard phraseology (e.g., "WE CAN'T TAKE TWO TWO RIGHT."). Fluency (e.g., dysfluency) was a factor in 15 messages. There also were two instances of comprehension problems involving ELP. No other problems with English language proficiency were identified. There were no BICs involving Foreign-English air carriers.

Likewise, for the pilots operating the U.S.-English registry aircraft, there was one instance where pronunciation was a factor and another instance involving vocabulary (e.g., "CAN WE BUMP IT UP?"). Fluency presented itself 18 times, and there were two instances in which comprehension was a problem. Finally, there were 12 instances where pilots responded to the controllers with unrelated messages.

DISCUSSION

ICAO required its language proficiency standards to be implemented in March 2008; however, member states that were not quite ready will be provided with a maximum 3-yr waiver, provided they submitted a testing program to ICAO by the March 5, 2008, deadline. The standards are designed to improve the pilot-controller communication process and will likely reduce the incidence of miscommunications. The development of these standards originated as a response to an increase in aviation fatalities and accidents with inadequate English language proficiency cited as either a causal or contributing factor.

The analysis of ATC verbal communications is a complex process that delves deeper and deeper into the layers of pilot-controller transactions. It can begin with a linguistic analysis of utterances and culminate in an

examination of the psycholinguistic and social aspects of language. Although much is known about the types of messages and communication problems within the current TRACON (Prinzo et al., 2007) and past en route (Cardosi, 1993) and tower (Burki-Cohen, 1995; Cardosi, 1994) environments, there is no distinction between problems experienced by pilots who fly U.S., as compared with foreign aircraft.

The purpose of this report is to provide some indication as to the types and frequency of communication problems experienced by U.S. and foreign pilots who may or may not have English as their primary or official language. To do this, facility representatives at five U.S. ARTCCs provided digital audio tape reproductions of the communications of pilots and controllers that occurred between March and August 2006. The communication samples were to contain heavy concentrations of international arrivals and departures at that facility and be communication rich. Aircraft call signs were identified as either U.S. or foreign registry, and then the official language of the country of registry was identified. In some cases, the aircraft was foreign and the primary or official language was English. Three different groups of transactions were examined: U.S.-English, Foreign-English, and Foreign-Other (non-English).

The prevalence of communication problems was compared among pilots flying 642 U.S. and 190 foreign registry aircraft by evaluating their messages from transcripts made from digitized copies of audio recordings provided by ARTCCs. Of the 190 foreign registry aircraft, 26 had English as their official language. All foreign aircraft, regardless of their primary language, spent about 6 s more on frequency communicating with ATC than U.S. aircraft. This additional time on frequency may be due in part from pilots transmitting more messages than the pilots flying U.S. registry aircraft. Some of these additional transmissions may have resulted from pilots with English as a second language experiencing more communication problems (per transaction) than the foreign and U.S. pilots who spoke English as their primary language.

To determine whether or not communication problems included messages with deficiencies in English language proficiency, an overall detailed analysis was performed on the pilot-controller transactions identified as having one or more communication problem. Generally, the encoder answered two questions: (1) Is there a communication problem? (yes or no); and (2) Was language proficiency involved? (yes or no). If the encoder believed that language proficiency was involved, then an attempt was made to classify ELP using the ICAO Language Proficiency Scales as a guide.

The communication problems were classified into three major categories: readback errors, requests for repeat, and breakdowns in communication. An examination of these communication problems showed that for U.S. registry aircraft transactions with one communication problem, 51% involved readback errors, 34% requests for repeat, and 15% breakdowns in communication. In contrast, 23% of the foreign registry aircraft transactions with one communication problem were readback errors, 62% were requests for repeat, and 14% involved breakdowns in communication. Of the transactions with multiple problems, over 75% involved foreign registry aircraft. Also, the majority of these transactions were found not to have problems (overall, only 23% had one or more communication problem).

It is important to restate that not all communication problems lead to, or contribute to, unsafe acts or undermine safety. The pilot-controller communication process is redundant; the pilot reads back the ATC transmission received on the flight deck while the controller listens for an accuracy recitation of the contents. If the readback is inaccurate, the controller may restate or otherwise clarify the original transmission. Often readback errors are resolved with the inclusion of two additional messages: one by the controller correcting the erroneous aviation topic and one by the pilot with correct recitation of that aviation topic.

Readback Errors

Among foreign registry aircraft, the more frequently occurring readback errors included radio frequency and route aviation topics. In 64% of the readback errors made by Foreign-Other registry aircraft pilots, their accents made it difficult for the controller to understand what was being said. For U.S. registry aircraft, the more frequently occurring readback errors involved radio frequency and altitude aviation topics, of which pronunciation was a factor for 1% of the readback errors.

Requests for Repeat

Likewise, pilots who are flying into unfamiliar areas, speaking with a different accent (i.e., they have to "put their ears on"), or have been up all night, may want verbal verification or confirmation when ATC messages involve multiple instructions, clearances, advisories, requests, or a combination of these speech acts. These requests for repetition involve two additional messages: one by the pilot querying the controller about the original transmission and one by the controller who provides the pilot with the requested information.

Nearly 63% of the requests to repeat a transmission involved the confirmation or "say again" of a particular

aviation topic, followed by a request to have the entire transmission repeated. Foreign and U.S. registry aircraft each wanted confirmation of radio frequencies, routes, and altitudes more than any of the other aviation topics. The following message expresses several factors that influenced the pilot's rationale for a request for repeat: "I I GOTTA APOLOGIZE IT'S EARLY IN THE MORNING AND MY BRAIN'S UH — THE PEN UH WHICH ISN'T WORKING WELL — UH YOU GOTTA READ IT AGAIN SLOWER."

Once again, pilot accent (36%) and dysfluency (49%) were associated with RfR among foreign registry aircraft when the primary language was not English. Message structure was a factor for two foreign and one U.S. request that involved the substitution of words/phrases that were inconsistent with standard phraseology. For example, in the pilot's message, "AND [FACILITY ID] WE GOT TOLD ON ONE TWO THREE FOUR FIVE TO SQUAWK ONE ZERO THREE FOUR IS THAT CORRECT?" A more appropriate request would be "CONFIRM SQUAWK ONE ZERO THREE FOUR." Once again, there were 23 instances in which pilots of U.S.-English registry aircraft exhibited some problems with fluency. In one case, when speaking, the pilot's words ran together, making it difficult to understand what was being said. None of the other ELP dimensions were represented in any other RfR. None of the other ELP dimensions were a problem for either U.S. or foreign registry aircraft.

Breakdowns in Communication

Unlike readback errors and requests for repeats, communication problems that involve a breakdown in communication may require multiple exchanges between the pilot and controller before the problem is identified, understood, acknowledged, and resolved. This process can add multiple messages to a transaction and might pose a safety issue when a meeting of the minds fails to occur (i.e., a common ground of understanding) between the pilot and controller. Hence, readback errors may result in part from memory overload (Baddeley, 1987; Miller, 1956), linguistic factors (e.g., articulatory duration, phonological similarity, and phonological complexity) (Mueller, Seynour, Kieras, and Meyer, 2003), number of aviation topics in a message (Barshi and Healy, 2002; Morrow and Prinzo, 1999), and possibly information complexity (Cardosi, 1993; but see Barshi, 1997). Likewise, requests for repeat may be due to these factors, as well as workload, station keeping tasks, distraction, divided attention, comprehension, understanding, caution, and other language-based issues (e.g., dialect influencing the intelligibility of the utterance, language proficiency).

Whereas both readback errors and requests for repeat involve a pair of transmissions, breakdowns in communication often involve more than two or three transmissions to reach a common ground of understanding. Isolating the source of the breakdown may reside with factors associated with readback errors and requests for repeat, as well as the faulty processing of the syntactic or semantic properties of an utterance, failure to successfully integrate ongoing information with information gleaned from previous utterances, understanding the context within which the action is to occur, prior knowledge, and other factors. Hopefully, either the speaker or receiver discovers that some portion of the transaction was misinterpreted and sets about to correct the misunderstanding. Whether communication problems begin with encoding/decoding processes that culminate with higher levels of cortical involvement is a theoretical issue not discussed here.

Of the transactions involving a breakdown in communication, runway assignment and route clearance transactions were especially problematic for the pilots of Foreign-Other registry aircraft. The problems may be partially due to controllers' use of plain language and the pilots' difficulties with pronunciation and fluency. Notably, the pilots' accents affected the intelligibility of 79% of their messages to ATC.

The presence of a problem in comprehension was more difficult to determine, as illustrated in Table 16. In both instances, the controller spoke to the pilot of a Foreign-Other registry aircraft in plain English rather than standard phraseology. It is uncertain whether the pilots understood what the controller was asking, as reflected by their responses ("STANDBY" and "BE BACK"). On one hand, it may be that the pilots needed time to check their charts, aircraft performance, weight and balance, and other factors not associated with language proficiency. On the other hand, it may be that the pilots of each aircraft were discussing among themselves what the controller said and what would be the appropriate response.

Had the controller said, "EXPECT RUNWAY [numbers] RIGHT" the pilot still might respond "STANDBY" or "UNABLE" if the runway did not meet the aircraft's requirements for a safe landing, or with "ROGER" if that runway was acceptable. There is an indication that the controller also had some difficulty understanding what the pilots were saying ("I'M SORRY … DID YOU SAY…" and "I'M SORRY WAS THAT AFFIRMATIVE OR NEGATIVE"). The first example required the exchange of 12 transmissions, whereas the second example contained seven transmissions. The controller needed this information to coordinate each aircraft's arrival routes to their destination airports.

The breakdowns in communication experienced by U.S.-English registry aircraft involved call sign confusion and the transfer of communication process (either a transfer occurred too soon or the controller had to initiate the call-up). Pronunciation and vocabulary rarely appeared in a breakdown of communication. Rather, fluency was

Table 16. Examples of Breakdowns in Communication.

SPKR	MESSAGE
	Example 1
ATC	FOREIGNSHIP EIGHT CAN YOU ACCEPT RUNWAY TWO TWO RIGHT AFFIRMATIVE OR NEGATIVE
FD8	***STANDBY ONE***
FD8H	FOREIGNSHIP EIGHT HEAVY WE CAN'T TAKE TWO TWO RIGHT
ATC	NEGATIVE OKAY YEAH PLAN ON HOLDING OVER {FIX} SIR
ATC	OH FOREIGNSHIP EIGHT UH CAN YOU TAKE TWO SEVEN RIGHT PLEASE
FD8	***UH {UNINTELLIGIBLE-P} TAKE EH RIGHT***
ATC	I'M SORRY FOREIGNSHIP EIGHT DID YOU SAY YOU ARE AFFIRMATIVE FOR TWENTY TWO RIGHT
FD8	NO I SAID NEGATIVE NEGATIVE FOR TWENTY TWO RIGHT
ATC	OKAY SOMEBODY GOT STEPPED ON FOREIGNSHIP EIGHT CAN YOU TAKE TWO TWO RIGHT FULL LENGTH AFFIRMATIVE OR NEGATIVE
FD8H	NEGATIVE WE CANNOT TAKE TWO TWO RIGHT FOREIGNSHIP EIGHT HEAVY
ATC	{COUGH} CAN YOU TAKE TWO SEVEN RIGHT SIR
FD8	UH AFFIRMATIVE WE ARE ABLE TWO SEVEN RIGHT
	Example 2
ATC	FOREIGNSHIP FIFTY CAN YOU ACCEPT RUNWAY TWO SEVEN RIGHT FULL LENGTH AFFIRMATIVE OR NEGATIVE
FD50H	BE BACK UH FOREIGNSHIP UH FIFTY HEAVY
ATC	FOREIGNSHIP FIFTY HEAVY I'M SORRY WAS THAT AFFIRMATIVE OR NEGATIVE FOR TWO SEVEN RIGHT FULL LENGTH
FD50H	NEGATIVE FOREIGNSHIP FIFTY HEAVY
ATC	OKAY UH ONE MORE TIME SIR AFFIRMATIVE OR NEGATIVE I'M MISSING PART OF YOUR TRANSMISSION
FD50H	NEGATIVE FOREIGNSHIP FIFTY HEAVY WE CANNOT ACCEPT
ATC	YOU CANNOT ACCEPT NEGATIVE OKAY THANK YOU

more likely to be an indicator of a problem — 25% of the 73 pilot transmissions were potentially problematic in language production.

In some cases, dysfluencies such as "UHS," "UMS," and "AHS" are indicators of uncertainty rather than disruptions to formulating an intelligible and fluent readback. For example, when ATC issued the following clearance, "U.S. OWNSHIP 753 RIGHT TURN DIRECT [fix] ON COURSE THANKS" the pilot responded appropriately with the transmission, "UH WE CAN MAKE A RIGHT TURN U.S. OWNSHIP UH 753 WE BUT UH TO [fix] NOT ON AIRWAY." In the example, the aircraft is on a particular arrival that does not include the fix mentioned by the controller. Had the pilot agreed to the route, a right turn would require a near 360-degree turn. The use of the hesitation, "UH" may serve as an alerting mechanism to the controller from the pilot that there is a problem with the clearance, not the pilot's language proficiency.

In contrast, in response to the controller query "FOREIGNSHIP EIGHT CAN YOU TAKE TWO SEVEN RIGHT PLEASE," the pilot replies with, "UH [unintelligible-P] TAKE EH RIGHT." The controller cannot understand the pilot, as evidenced by the controller's next transmission, "I'M SORRY FOREIGNSHIP EIGHT DID YOU SAY YOU ARE AFFIRMATIVE FOR TWENTY TWO RIGHT?" In this example, the "UHS" may be more indicative of the pilot's difficulty with the English language than with an incongruence between the filed flight plan and the controller's instruction. In fact, the use of "UH" by the speaker serves the role of a placeholder to the hearer of the transmission that the speaker may be searching the mental lexicon for the correct word.

To summarize, in ATC radiotelephone communication, it is difficult to differentiate between language, ATC phraseology, and the traffic situation. Controller-pilot communication is not a casual exchange of information — messages carry weight of importance, i.e., **safety**. The requirement to repeat a message, pay close attention, or request a repeat of message does not necessarily create a communication problem, nor do any of the following: (1) the ATC message does not match pilot expectation; (2) the ATC message may not correlate with the flight path; (3) the use of nonstandard phraseology by either the controller or pilot;

(4) equipment problems, poor transmission quality; (5) the microphone technique used by either the controller or pilot; and (6) the speech production of either the controller or pilot (e.g., speech rate, stammering, pausing, words running together).

A communication problem is a situation in which a message is not understandable in content, speech (accent), structure, or any combination of content, speech, and structure that reaches the level of interfering with traffic procedures. A communication problem may create an ATC problem; however, an ATC problem rarely creates a communication problem. Communication problems were encoded that resulted in interference with traffic procedures, required plain language to resolve, or required assistance from other pilots or ATC to convey the message, or the encoder believed that communication had broken down. An example of an ATC problem independent of a communication problem would be an aircraft cleared for departure that stalls on the runway while another aircraft has received its approach clearance to that same runway. The aircraft on approach would have to receive instructions to "GO AROUND" if the other aircraft fails to clear the runway. Likewise, having to vector aircraft around a weather front would be an ATC problem.

The findings presented here revealed that foreign registered aircraft with a language other than English as their primary or official language, that received ATC services in the U.S., not only spent more time on the radio communicating with ATC, but more transmissions were exchanged and more communication problems were present within their transactions. The additional pilot messages may have resulted from attempts to resolve some of the communication problems. In these situations, a pilot's English proficiency — especially his/her accent — often resulted in the controller not being able to completely understand what the pilot was attempting to say. Rarely did the controllers express difficulty understanding an English-speaking pilot. An overall examination of the pilots' English language proficiency indicates that the accents of pilots flying for Foreign-Other aircraft was a limiting factor, while for pilots flying for U.S.-English aircraft, dysfluencies were fairly common.

These findings are congruent with a recent content analysis that was conducted on communication between Thai controllers and local Thai pilots, native English-speaking pilots (e.g., U.S., British), and non-native English-speaking pilots (e.g., Korean, Japanese). In that study, Tiewtrakul (2007) found that the local Thai ATC accent affected pilot understanding. In particular, there were more communication problems (readback errors, requests for repeats, and no responses) among the non-native English-speaking pilots (9.5%), followed by native English-pilots (4.8%). The least problems occurred among the Thai or local pilots (1.4%). Tiewtrakul concluded that the Thai controllers' native language may have influenced their English pronunciation to the point that non-native Thai-speaking pilots were at a disadvantage in understanding what was spoken.

Taken together, the results suggest that being able to speak English may be necessary but is not sufficient in limiting communication problems. The proficiency of the speaker in the production of English beyond the minimum specified in the ICAO language proficiency scales must be realized if communication problems are to decline.

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APPENDIX A

Pilot Readback Error Guide

As used here, a readback error is defined as an unsuccessful attempt by a pilot to read back correctly the information contained in the communication elements that comprise the original message transmitted by air traffic control. The readback errors are illustrative replies made by a hypothetical aircraft.

Classification of Readback Errors	Examples
Readback Errors Type (ALT)	
ATC: "American Ten climb and maintain one two thousand"	
1 = Substitution of message numbers/flight level vs. thousand	1-"maintain one three thousand" "maintain flight level one two"
2 = Substitution-transposition of climb/descend	2-"descend maintain one two thousand"
3 = Substitution of message numbers with incorrect climb/descend	3-"descend maintain one three thousand"
4 = Transposition of message numbers with incorrect climb/descend	4-"descend maintain two one thousand"
5 = Transposition of message numbers	5-"climb maintain two one thousand"
6 = One type of information read back as another type of information	6-"one two zero knots"
7 = Omission of anchor word(s)	7-"one two"
8 = Omission of number elements	8-"climb maintain"
9 = Omission of anchor word(s) and some number elements	9-"climb two thousand"
Readback Errors Type (ALT RSTRN)	
ATC: "American Ten cross Alpha at or above one two thousand"	
1 = Substitution of message numbers/rate of descent/climb, substitution of word "expedite"	1-"cross Alpha at or above one three thousand"
2 = Substitution of (*point/fix*)	2-"cross Bravo at or above one two thousand"
3 = Substitution of message numbers with incorrect *(point/fix)*	3-"cross Bravo at or above one three thousand"
4 = Transposition of message numbers with incorrect *(point/fix)*	4-"cross Bravo at or above two one thousand"
5 = Transposition of message numbers	5-"cross Alpha at or above two one thousand"
6 = One type of information read back as another type of information	6-"descend to one two thousand"
7 = Omission of anchor word(s)	7-"cross *(point/fix)* at one two" "*(point/fix)* at one two thousand"
8 = Omission of message numbers and/or *(point/fix)*	8-"cross at one two thousand" "cross *(point/fix)* at one two"
9 = Omission of anchor word(s) and some number elements and/or *(point/fix)*	9-"cross VOR at one two"

Note: "*Expedite*" *clearances — Readbacks should include the word* "*expedite.*" ATC: "AAL Ten expedite climb to one two thousand," to which the FD replies: 'hurry up to one two thousand'	
Classification of Readback Errors	**Examples**
Readback Errors Type (ALTM)	
ATC "AAL Ten {Source} altimeter two nine nine two"	
1 = Substitution of message numbers	1-"altimeter nine two nine zero"
2 = Transposition of message numbers	2-"altimeter nine two two nine"
6 = One type of information read back as another type of information	6-"squawk two nine nine two"
7 = Omission of anchor word	7-"*(source)* two nine nine two"
8 = Omission of number elements	8-"*(source)* altimeter nine two"
9 = Omission of both anchor word(s) and some number elements	9-"*(source)* nine nine two"
Readback Errors Type (FREQ)	
ATC: "American Ten contact center one one eight point three"	
1 = Substitution of message numbers, (*facility), (point/fix)*	1-"contact center one eight"
2 = Substitution - transposition of message numbers	2-"contact center one eight one point three"
3 = Substitution of message numbers with incorrect *(facility), (point/fix)*	3- "contact tower one two eight point three"
4 = Transposition of message numbers with incorrect *(facility), (point/fix)*	4-"contact tower one eight one point three"
5 = Transposition of message numbers	5-"contact center eight one one point three"
6 = One type of information read back as another type of information	6-"squawk one one eight three"
7 = Omission of anchor word(s)	7-"contact center one one eight three"
8 = Omission of number elements	8-"contact center one eight point three"
9 = Omission of both anchor word(s) and some number elements	9-"contact center one eight three"
Readback Errors Type (HDG)	
ATC: "American Ten turn left heading two one zero"	
1 = Substitution of message numbers	1-"zero one zero" or "six zero"
2 = Substitution of direction of turn	2-"turn right heading two one zero"
3 = Substitution of message numbers with incorrect direction of turn	3-" turn right one three zero"
4 = Transposition of message numbers with incorrect direction of turn	4-"turn right heading one two zero"
5 = Transposition of message numbers	5-"turn left heading one two zero"
6 = One type of information read back as another type of information	6-"two one zero knots"
7 = Omission of anchor word(s)	7-"two one zero"
8 = Omission of number elements	8-"turn left heading" "left on the heading"
9 = Omission of both anchor word(s) and some number elements	9-"two one"

Classification of Readback Errors	Examples
Readback Errors Type (HDG MOD)	
ATC: "American Ten increase rate of turn descend maintain four thousand"	
1 = Substitution of rate of turn	1-"decrease rate of turn"
Readback Errors Type (HLDG)	
ATC: "American Ten hold northeast Alpha one zero mile legs right turns"	
1 = Substitution of message numbers, *(fix/waypoint), (direction),* etc.	1-"hold southwest Alpha"
2 = Substitution - transposition of message numbers	
3 = Substitution of message numbers with incorrect *(fix/waypoint), (direction),* etc.	3-"southwest Bravo one two mile legs"
4 = Transposition of message numbers with incorrect *(fix/waypoint), (direction),* etc.	
5 = Transposition of message numbers	
6 = Other-one type of information read back as another type of information	6-"via Victor twelve"
7 = Omission of *(fix/waypoint), (direction), (course), (minutes/miles),* etc.	
8 = Omission of number elements	
9 = Omission of *(fix/waypoint), (direction), (course), (minutes/miles),* etc. and some number elements	
Readback Errors Type (RTE)	
ATC: "American Ten via Victor nine J twenty eight Alpha" **ATC: "AAL Ten via Victor twelve J twenty eight *(fix)*"** **ATC: "AAL Ten turn right direct *(fix)*"**	
1 = Substitution of message numbers, *(fix), (route)*	1-"via Victor five J twenty eight Alpha"
2 = Substitution - transposition of message numbers	2-"via Victor nine J eighty two Alpha"
3 = Substitution of message numbers with incorrect *(fix), (route)*	3-"via Victor eight J twenty eight to Bravo"
4 = Transposition of message numbers with incorrect *(fix), (route)*	4-"via Victor nine J eighty two to Bravo"
5 = Transposition of message numbers	5-"via Victor nine J eighty two Alpha"
6 = One type of information read back as another type of information	6-"altimeter's nine twenty eight"
7 = Omission of *(fix)*/aircraft	7-"twelve twenty eight"
8 = Omission of part/all of route	8-"Victor and the J route *(fix)*" "(*fix)*"
9 = Omission of *(fix)*/aircraft and part/all of route	9-"Victor and twenty eight"

Classification of Readback Errors	Examples
Readback Errors Type (SPD)	
ATC: "American Ten reduce speed two one zero knots"	
1 = Substitution of message numbers	1-"two five zero knots"
2 = Substitution - transposition of message numbers	2-"reduce one two zero knots"
3 = Substitution of message numbers with incorrect increase/decrease	3-"increase speed two five zero knots"
4 = Transposition of message numbers with incorrect increase/decrease	4-"increase one two zero knots"
5 = Transposition of message numbers	5-"reduce one two zero knots"
6 = One type of information read back as another type of information	6-"heading two one zero"
7 = Omission of anchor word(s)	7-"reduce two one zero"
8 = Omission of number elements	8-"reduce speed"
9 = Omission of both anchor word(s) and some number elements	9-"reduce two one"
Readback Errors Type (TRNSPNDR)	
ATC: "American Ten squawk two one two four"	
1 = Substitution of message numbers	1-"squawk four two one three"
2 = Substitution - transposition of message numbers	2-"squawk one two two four"
6 = Other - one type of information read back as another type of information	6-"altimeter two one two four"
Readback Errors Type (Advisory:APRCH/DEPTR)	
ATC: "American Ten expect ILS runway two one right approach"	
1 = Substitution of message numbers	1-"expect ILS runway two two right approach"
2 = Substitution - transposition of message numbers	2-"expect ILS runway one two right approach"
3 = Substitution of approach name	3-"expect visual approach"
6 =Other - One type of information read back as another type of information	6-"expect maintain two one"

APPENDIX B

MANOVA, ANOVA, and Fisher LSD Statistical Output of Throughput Analysis

Multivariate Tests(c)

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.559	349.587(a)	3.000	827.000	.000
	Wilks' Lambda	.441	349.587(a)	3.000	827.000	.000
	Hotelling's Trace	1.268	349.587(a)	3.000	827.000	.000
	Roy's Largest Root	1.268	349.587(a)	3.000	827.000	.000
REGISTRY_LANGUAGE	Pillai's Trace	.088	12.663	6.000	1656.000	.000
	Wilks' Lambda	.913	12.863(a)	6.000	1654.000	.000
	Hotelling's Trace	.095	13.062	6.000	1652.000	.000
	Roy's Largest Root	.088	24.251(b)	3.000	828.000	.000

a Exact statistic
b The statistic is an upper bound on F that yields a lower bound on the significance level.
c Design: Intercept+REGISTRY_LANGUAGE

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Prob_total_sum	6.501(a)	2	3.251	5.227	.006
	TOTSEC_sum	5413.482(b)	2	2706.741	31.511	.000
	N_BREAK	131.039(c)	2	65.520	8.416	.000
Intercept	Prob_total_sum	21.839	1	21.839	35.114	.000
	TOTSEC_sum	60062.761	1	60062.761	699.223	.000
	N_BREAK	7701.477	1	7701.477	989.277	.000
REGISTRY_LANGUAGE	Prob_total_sum	6.501	2	3.251	5.227	.006
	TOTSEC_sum	5413.482	2	2706.741	31.511	.000
	N_BREAK	131.039	2	65.520	8.416	.000
Error	Prob_total_sum	515.594	829	.622		
	TOTSEC_sum	71210.513	829	85.899		
	N_BREAK	6453.730	829	7.785		
Total	Prob_total_sum	617.000	832			
	TOTSEC_sum	263764.000	832			
	N_BREAK	34462.000	832			
Corrected Total	Prob_total_sum	522.095	831			
	TOTSEC_sum	76623.995	831			
	N_BREAK	6584.769	831			

a R Squared = .012 (Adjusted R Squared = .010)
b R Squared = .071 (Adjusted R Squared = .068)
c R Squared = .020 (Adjusted R Squared = .018)

Multiple Comparisons

LSD

Dependent Variable	(I) REGISTRY-LANGUAGE	(J) REGISTRY-LANGUAGE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Prob_total_sum	U.S.-English	Foreign-English	.1068	.15776	.499	-.2029	.4164
		Foreign-Other	-.2131(*)	.06900	.002	-.3486	-.0777
	Foreign-English	U.S.-English	-.1068	.15776	.499	-.4164	.2029
		Foreign-Other	-.3199	.16647	.055	-.6466	.0069
	Foreign-Other	U.S.-English	.2131(*)	.06900	.002	.0777	.3486
		Foreign-English	.3199	.16647	.055	-.0069	.6466
TOTSEC_sum	U.S.-English	Foreign-English	-5.6586(*)	1.85408	.002	-9.2979	-2.0194
		Foreign-Other	-6.1394(*)	.81091	.000	-7.7311	-4.5477
	Foreign-English	U.S.-English	5.6586(*)	1.85408	.002	2.0194	9.2979
		Foreign-Other	-.4808	1.95642	.806	-4.3209	3.3594
	Foreign-Other	U.S.-English	6.1394(*)	.81091	.000	4.5477	7.7311
		Foreign-English	.4808	1.95642	.806	-3.3594	4.3209
N_BREAK	U.S.-English	Foreign-English	-1.23(*)	.558	.027	-2.33	-.14
		Foreign-Other	-.89(*)	.244	.000	-1.37	-.41
	Foreign-English	U.S.-English	1.23(*)	.558	.027	.14	2.33
		Foreign-Other	.34	.589	.559	-.81	1.50
	Foreign-Other	U.S.-English	.89(*)	.244	.000	.41	1.37
		Foreign-English	-.34	.589	.559	-1.50	.81

Based on observed means.

* The mean difference is significant at the .05 level.