PREFACE

We thank the Federal Aviation Administration Office of the Chief Scientist for Human Factors (AAR-100) for supporting this and other air traffic control (ATC) communications work. Bryan Brett of Science Applications International Corporation (SAIC) coordinated the voice-tape and raw-data analysis, and, together with Dave Malek, promptly fielded many follow-up questions. Ben Cameron, John Chevalier, Joe Jarboe, and Joe Moyer, also from SAIC, analyzed the voice tapes. We appreciate their effort in this difficult and sometimes tedious task. Dr. Kim Cardosi provided insightful comments on an earlier draft of this report. Finally, we thank the quality assurance specialists at the participating ATC facilities who supplied the tapes for this analysis.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	=	1.1 short tons

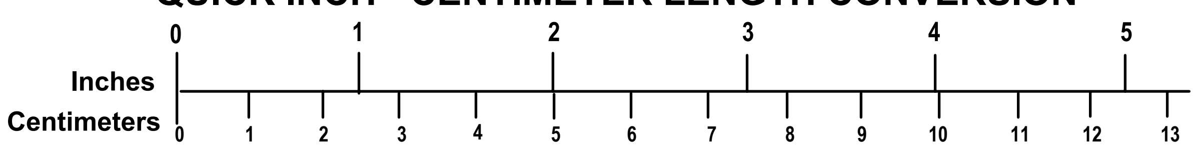
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



Error! Switch argument not specified.

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

Error! Switch argument not specified.

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 1/23/95

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EXECUTIVE SUMMARY

This analysis of ground-control communications is part three of a four-part effort to capture not only the qualitative, but also the quantitative aspects, or incidence, of air traffic control miscommunications. The approach taken is to examine representative samples of pilot-controller communications recorded in four air traffic control (ATC) environments; tower-ground control (this report), air route traffic control centers (Cardosi, 1993), tower-local control (Cardosi, 1994), and terminal radar control (TRACON) (in progress).

Despite initial applications of datalink,[1] voice communications between air traffic controllers and pilots remain at the center of ATC operations. Given this prominent role, it is not surprising that communication problems have been identified as a factor in over 70 percent of operational errors and pilot deviations in the FAA's Operational Error and Deviation System (OEDS) (Danaher, 1993). Accidents such as the 1977 collision between two Boeing 747s at Tenerife, demonstrate the potentially fatal consequences of inadequate communication. (One aircraft taxied down the runway while the other used the same runway for an unauthorized takeoff.) Additional evidence for communication problems stems from incidents reported to the Air Safety Reporting System (ASRS; see, e.g., Monan, 1988). Although evidence from such (potential) accidents and incidents is very valuable for pinpointing and/or investigating specific areas of concern, it represents a biased sample, counting only the cases in which something went awry.

At the Department of Transportation's Volpe Center for Transportation Human Factors Research, we are taking a three-pronged approach to the investigation of air-traffic control communications. In addition to communication problems reported to the ASRS, we are examining voice tapes recorded at ATC facilities during actual operations. This endeavor is the subject of the present report. Furthermore, we are verifying some of the conclusions drawn from the two previous approaches and investigating other issues relevant to effective controller-pilot communication in carefully controlled laboratory studies (see, e.g., Bürki-Cohen, 1995 a, b).

This report is based on an analysis of over 48 hours of pilot-controller communications recorded from the ground-control frequency at twelve air traffic control towers. We examined the complexity of controller instructions, that is, how many pieces of information a single controller transmission contains. We also looked at how pilots respond to these instructions, and whether the type of response is affected by the complexity of the instructions. Particularly, we studied the effect of complexity of the instructions on communication problems, such as when pilots ask controllers to repeat their instructions or when they make an error in the readback. Other communication problems examined include aircraft callsign discrepancies and conceptual errors (e.g., when a controller sends a pilot to the wrong runway or a pilot dials in the wrong frequency.)

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1. For example, Digital Automatic Terminal Information Service (ATIS) and pre-departure clearances (ACARS, AIRINC Communications Addressing and Reporting Systems).

The following recommendations to further improve ATC communications and thus the margin of safety in the ground-control environment arise from this investigation:

1. Controllers should keep instructions short. The shorter an instruction, the more likely will it be correctly read back by the pilot.

2. Controllers should listen to what a pilot reads back, especially regarding hold-short and taxi instructions and frequencies. More emphasis should be given to hearback during controller training (ASRS Callback, 1992).

3. Controllers should try to speak slowly *especially* when they are under pressure and don't have time to repeat information.

4. When talking to foreign pilots, controllers should take into account the potential for phraseology differences and reduced English language proficiency. The FAA should compile a list phraseology differences to be distributed to controllers *and* pilots, especially those flying internationally. Controllers also should speak *"staccato,"* that is, to break the instruction up into its component words by inserting short pauses. Recognizing where one word ends and the next begins is notoriously difficult for any inexperienced listener of a foreign language. Repeating numbers in grouped format, i.e., "seven-teen," instead of sequential format, "one seven," as recently authorized for emphasis of altitudes (FAA, 1992), may backfire with foreign pilots who group numbers differently in their native language.

5. Pilots should ask when they are not sure about a piece of information. But even if pilots are sure that they have heard and remembered correctly, they should at least read back hold-short instructions and frequency changes.

6. Whenever possible, controllers should point out similar callsigns on the same communication frequency. All instructions and readbacks should include the full callsign.

7. Both controllers, when listening to readbacks, and pilots, when taking instructions, should be aware of how their expectations may affect what they hear. Pilots expecting certain instructions must wait for complete aircraft identification before taking action on the instructions.

1. INTRODUCTION

Despite initial applications of datalink,[2] voice communications between air traffic controllers and pilots remain at the center of air traffic control (ATC) operations. Given this prominent role, it is not surprising that communication problems have been identified as a factor in over 70 percent of operational errors and pilot deviations in the FAA's Operational Error and Deviation System (OEDS) (Danaher, 1993). Accidents such as the 1977 collision between two Boeing 747s at Tenerife, where one aircraft taxied down the runway while the other used the same runway for an unauthorized takeoff, demonstrate the potentially fatal consequences of inadequate communication. Additional evidence for communication problems stems from incidents reported to the Air Safety Reporting System (ASRS; see, e.g., Monan, 1988). Although evidence from such (potential) accidents and incidents is very valuable for pinpointing and/or investigating specific areas of concern, it represents a biased sample, counting only the cases in which something went awry. At the Department of Transportation's Volpe Center for Transportation Human Factors Research, we are taking a three-pronged approach to the investigation of air-traffic control communications. In addition to communication problems reported to the ASRS, we are examining voice tapes recorded at ATC facilities during actual operations. This endeavor is the subject of the present report. Furthermore, we are verifying some of the conclusions drawn from the two previous approaches and investigating other issues relevant to effective controller-pilot communication in carefully controlled laboratory studies (see, e.g., Bürki-Cohen, 1995 a, b).

This analysis of ground-control communications is part three of a four-part effort to capture not only the qualitative, but also the quantitative aspects, or incidence, of air traffic control miscommunications. The approach taken is to examine representative samples of pilot-controller communications from four ATC environments: tower-ground control (this report), air route traffic control centers (Cardosi, 1993), tower-local control (Cardosi, 1994), and terminal radar control (TRACON) (in progress).

The Federal Aviation Administration (FAA) lists communications as a primary factor causing runway incursions (Runway Incursion Plan, 1991). Although runway incursions are rare events, the same document reports a 39 percent increase in runway incursions at towered airports for the first eleven months of 1990 (249 incursions) compared to 1988 (179 incursions). The present report is based on a study of over 48 hours of pilot-controller communications recorded from the ground frequency at twelve air traffic control towers. It examines the complexity of controller instructions, that is, how many pieces of information a single controller transmission contains. It looks at how pilots respond to these instructions, and whether the type of response is affected by the complexity of the instructions. Particularly, it studies the effect of complexity of the instructions on communication problems, such as when pilots ask controllers to repeat their instructions or when they make an error in the readback. It also examines the incidence and possible causes of callsign confusions as well as of conceptual errors (such as when a pilot dials in the wrong frequency or a controller sends a pilot to the wrong runway) in pilot-controller communications. Lastly, it compares the incidence of communication problems with the

2. For example, Digital Automatic Terminal Information Service (ATIS) and pre-departure clearances (ACARS, AIRINC Communications Addressing and Reporting Systems).

transmission density (transmissions per minute) at a facility. It relates these findings to what has been found in the en-route (Cardosi, 1993), terminal-radar (TRACON; Morrow, Lee, and Rodvold, 1993), and in the tower-local control (Cardosi, 1994) environment. In conclusion, a series of recommendations is presented.

2. MATERIALS

Over 48 hours of ground air-traffic communications were examined. Twelve different ground-control facilities provided the tapes. The facilities were selected to cover a wide range of geographical locations, possible regional accents, workload levels, and traffic mixes (general aviation, airlines, and international traffic). Table 1 lists the facilities with the number of hours and transmissions examined, and also the average transmission density (transmissions per minute). The facilities are sorted in ascending order of the average transmission density. The average transmission density ranges from four transmissions per minute at Baltimore-Washington ground control to 12 transmissions per minute at Boston Logan ground control. All tapes were recorded during periods of busy traffic, as defined by the facility.[3]

TABLE 1. TRANSMISSIONS AND TRANSMISSION DENSITIES AT EACH FACILITY.

TOWER	HOURS	TRANSMISSIONS	TRANSMISSIONS PER MINUTE
Baltimore-Washington	3.63	858	3.94
Albuquerque	3.11	1,074	5.75
Atlanta	6.90	2,636	6.36
Dallas-Ft. Worth	4.13	1,590	6.42
Dulles	2.06	795	6.45
Seattle	4.13	1,758	7.09
Chicago	4.11	1,845	7.48
Philadelphia	2.05	988	8.03
Pittsburgh	4.07	2,226	9.12
Los Angeles	4.15	2,447	9.84
Miami	4.03	2,575	10.64
Boston	6.15	4,432	12.01
All	48.51	23,224	7.98

3. Please note that the transmission density rank order of these facilities correlates only very weakly (Pearson r_{xy}=.40) with the rank order based on total annual operations, which is led by Chicago O'Hare, followed by Dallas Ft. Worth, Los Angeles, Atlanta, and, with other airports in between, Miami and Boston (FAA, 1993).

As shown in Table 2, the total of 23,224 transmissions examined included 10,208 controller-to-pilot transmissions and 12,221 pilot-to-controller transmissions. Transmissions between controllers and ground vehicles were not examined in this study. A transmission is a single continuous communication by a speaker, whatever its length.

TABLE 2. TRANSMISSION DISTRIBUTION BY SENDERS AND RECEIVERS.

Controller-Pilot	Pilot-Controller	Controller-Ground Vehicle	Ground Vehicle-Controller	All
10,208	12,221	403	392	23,224

Of the 10,208 controller-pilot transmissions, two thirds (6,841) were taxi instructions. The remaining transmissions were initial contacts, questions or requests, answers to questions and requests, and weather or traffic advisories.

Of the 12,221 pilot-controller transmissions, more than half (6,432) were responses to instructions. The remaining transmissions were initial contacts, position reports, questions or requests, and answers to questions and requests.

The tape analysis was conducted by a former controller and three pilots. They identified and transcribed all communication errors, which were then analyzed separately by the author.

3. CONTROLLER INSTRUCTIONS

Figure 1 shows the relative frequencies of controller instructions at each complexity level. The complexity level was computed by counting all elements containing information a pilot has to remember, such as taxiways, runways, who to follow, but not items such as aircraft and facility identification, "Roger," or salutations. For example, the instruction "(Aircarrier) 3890, (Facility) Ground, give way to the second Dornier inbound, then taxi runway 32 left, intersection departure at Gulf, via outer, Charlie, Gulf" was coded as containing the following eight elements: Give way, Traffic, Runway, Other, Location, Taxiway 1, Taxiway 2, Taxiway 3. Although most of the instructions contained three or fewer pieces of information, over 35 percent contained four or more elements.

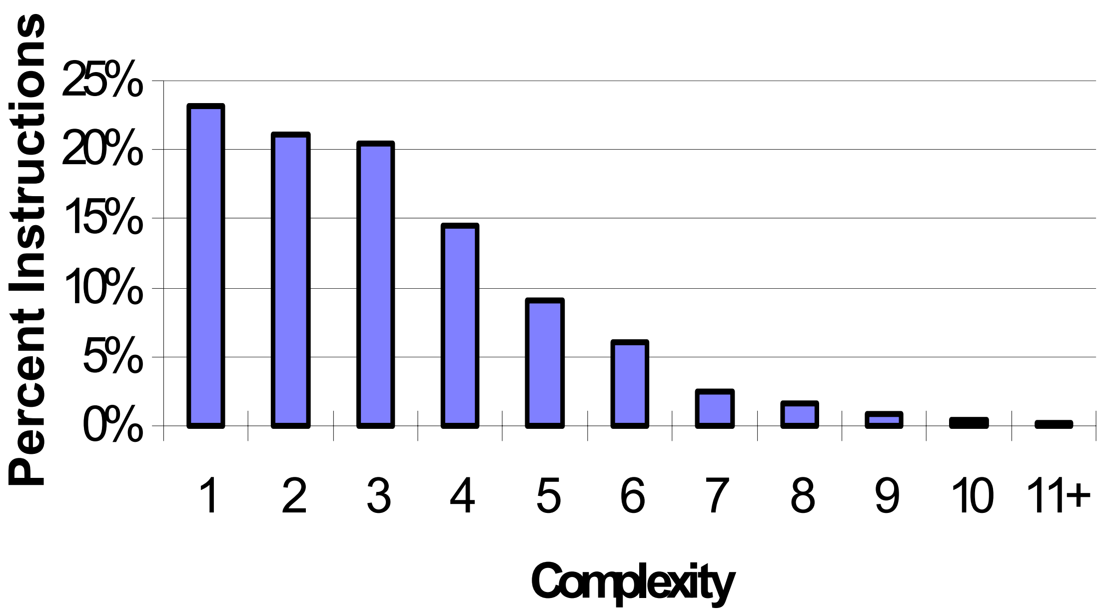

FIGURE 1. PERCENT CONTROLLER INSTRUCTIONS AT EACH COMPLEXITY LEVEL.

4. PILOT RESPONSES

4.1 OVERVIEW

Figure 2 shows pilots' responses to the 6,841 taxi instructions issued by ATC. One third (32 percent) of the instructions were acknowledged with a full readback, allowing the ground controller to verify pilots' correct perception and recall of the information through "hearback." Another third (33 percent) of the instructions were acknowledged with an equivalent of "Roger," "O.K., thanks," or callsign only. The remaining instructions were followed by a partial readback (16 percent), requests for repeat (fewer than two percent), other replies (10 percent), or no response at all (8 percent). The fact that only one third of the instructions were acknowledged with a full readback needs to be kept in mind when looking at the low incidence of readback errors (Section 5).

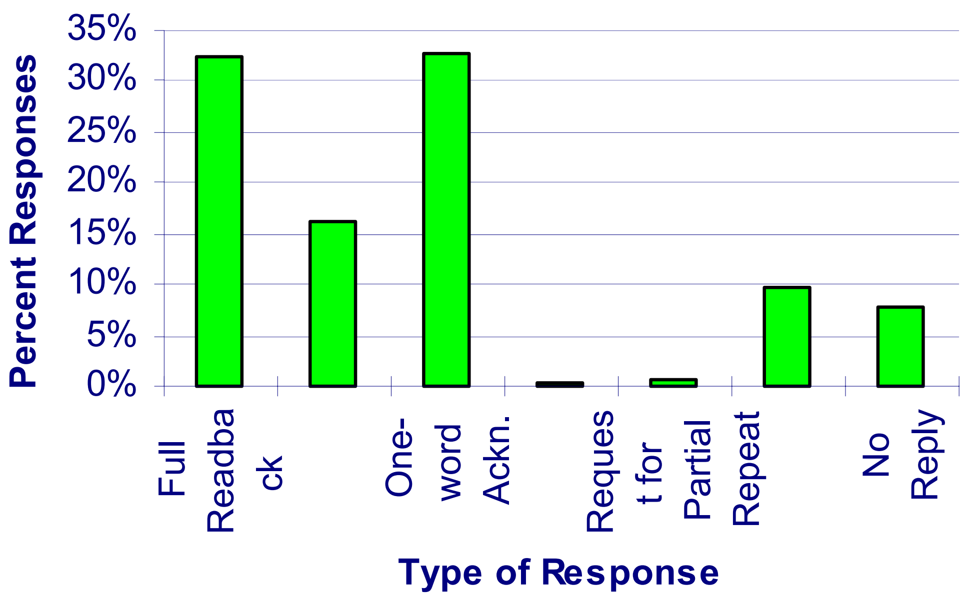

FIGURE 2. PERCENT PILOT RESPONSES FOR EACH TYPE OF RESPONSE.

4.2 EFFECT OF COMPLEXITY ON TYPE OF RESPONSE

Figure 3 shows the distribution of full and partial readbacks and one-word acknowledgments over complexity levels. The effect of instruction complexity on requests for repeats will be discussed in the section on communication problems.

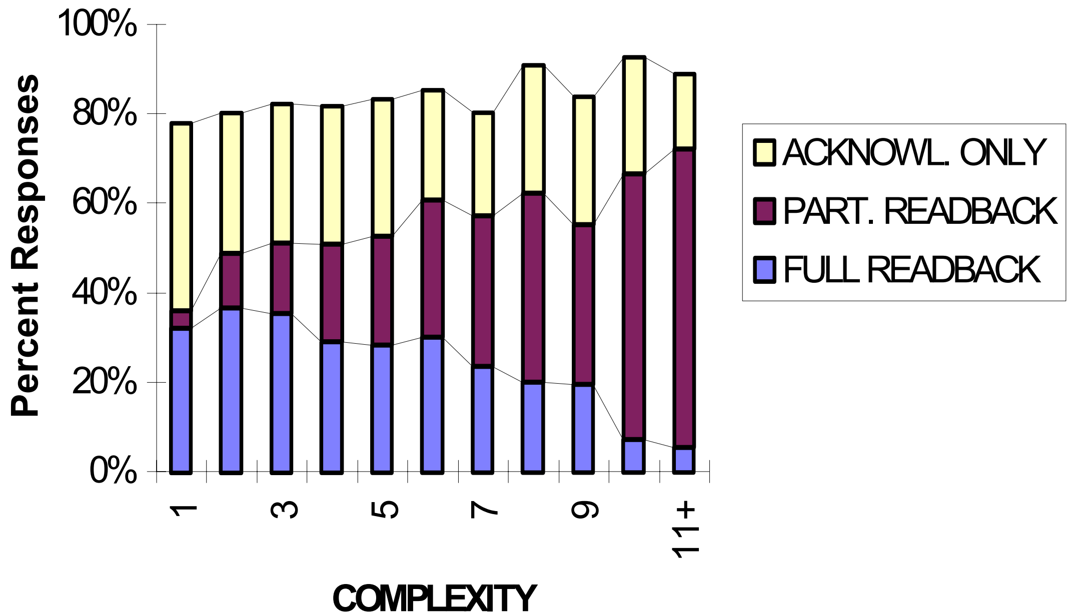

FIGURE 3. PERCENT OF THE THREE MOST FREQUENT PILOT RESPONSES TO INSTRUCTIONS AT EACH COMPLEXITY LEVEL.

As can be clearly seen, when instructions became more complex, the percentage of partial readbacks sharply increased, whereas the percentage of full readbacks decreased (Pearson r_{xy}=.96 and -.90, respectively; i.e., 92 and 81 percent of the change was accounted for by the increase in complexity).[4]

The percentage of one-word acknowledgments also decreased with increasing complexity, but only slightly more than half of this decrease was accounted for by an increase in complexity of the ATC instructions (Pearson r_{xy}=.72).

4. This and all other statistical analyses using Pearson r show to what degree the incidence of the different response types changed together with the complexity of the instructions, but do not inform on the causality of the relationship.

Similarly, fewer of the more complex instructions were not acknowledged, but now less than half of this decrease was accounted for by the complexity increase (Pearson r_{xy}=.70). Other types of responses (such as comments, questions, or requests other than for repeating the instructions) very slightly increased with instruction complexity (Pearson r_{xy}=.47).

5. COMMUNICATION PROBLEMS

5.1 OVERVIEW

In this section, any interruption of the ideal controller-pilot communication sequence, that is, accurate instructions from the controller that are understood and correctly read back by the pilot to whom they were addressed, will be discussed. This includes requests from the pilot that the controller repeat the instructions, misunderstandings by the pilot that result in erroneous readbacks, failure of the controller to recognize erroneous readbacks (hearback errors), confusion of the callsign either by the controller or the pilot, and conceptual errors such as a controller sending a pilot to the wrong runway or a pilot dialing in the wrong frequency. Some errors were corrected within a transmission, e.g., "Ground ASE 395, 5 north, correction, 4 north with tango". While this type of error may represent a cognitive load on the receiver of the message and contribute to congestion of the communication frequencies, it was not classified as a communication problem.

5.2 REQUESTS FOR REPEATS

For 76 of the 6,841 taxi instructions (one percent), pilots requested full or partial repeats. Figure 4 shows the percent requests for repeats at each complexity level. The need for full or partial repetition of instructions increased with the complexity of the instructions from one to eight pieces of information in a single instruction (Pearson r_{xy}=.73, i.e., over 50 percent of the increase was accounted for by the increase in complexity).

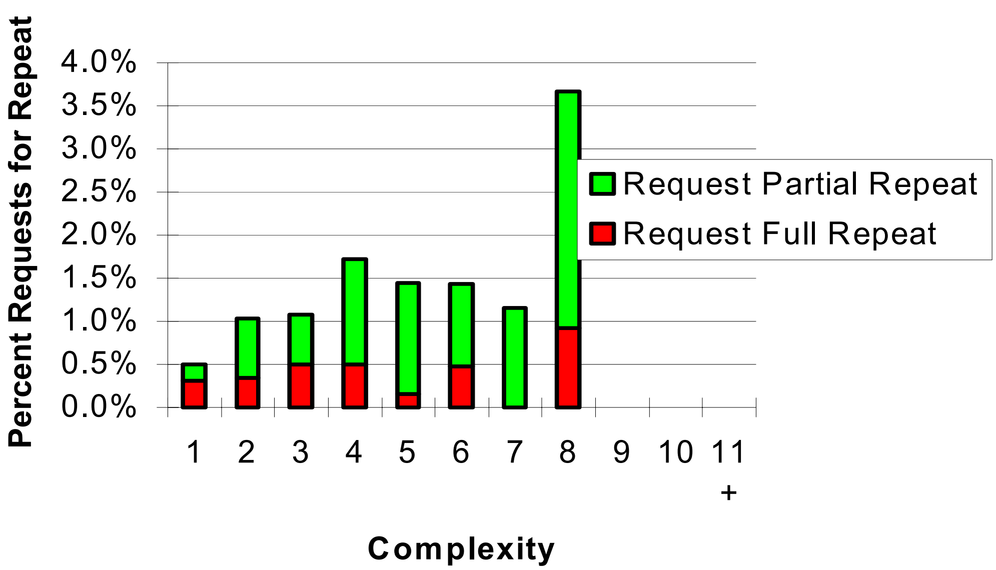

FIGURE 4. PERCENT REQUESTS FOR REPEAT OF THE INSTRUCTIONS AT EACH COMPLEXITY LEVEL.

5.3 READBACK/HEARBACK ERRORS

Twenty-six of the 3,313 full and partial readbacks contained errors, that is, fewer than one percent. Two of these communications contained two readback errors. The total error count was thus 28.

The distribution of readback and hearback errors as a function of the complexity of the instructions that were read back is shown in Figure 5. The errors are expressed in percent of the combined full and partial readbacks (i.e., opportunities for errors), at a given complexity level. The Pearson r_{xy} of .87 (calculated over complexity levels 1 through 7) shows that three quarters of the increase in readback errors are accounted for by the complexity increase.

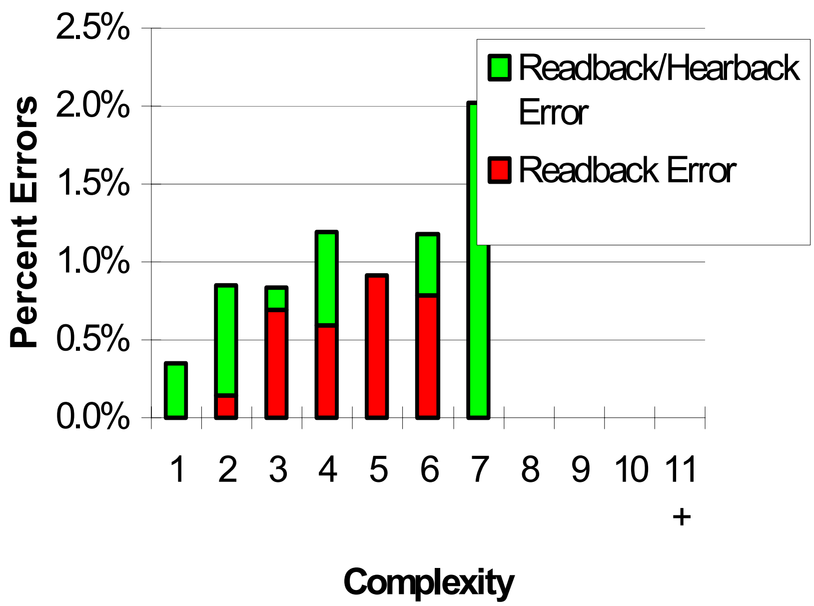

FIGURE 5. PERCENT ERRORS IN THE READBACK AND HEARBACK OF THE INSTRUCTIONS AT EACH COMPLEXITY LEVEL.

Fourteen or half of the readback errors were both corrected by the controller and the corrections were acknowledged by the pilot. In 16 cases the controller corrected the readback by repeating the information in error. Only two of these corrections were not explicitly acknowledged. Twelve errors, however, were not corrected by the controller (hearback errors). Some of them contained critical information. For one of these errors, where the pilot read back an instruction to hold short of a runway giving the wrong runway, the controller requested a repeat, but did not notice that the pilot omitted the runway to hold short of in his repeat.

Figure 6 shows the distribution of errors with regard to the type of information in error. Eight of the readback errors involved hold-short instructions (limits), eight the taxi route (including one runway crossing), five frequencies, three the sequence, three contained an erroneous runway, and one the wrong ATIS (Automatic Terminal Information Service).

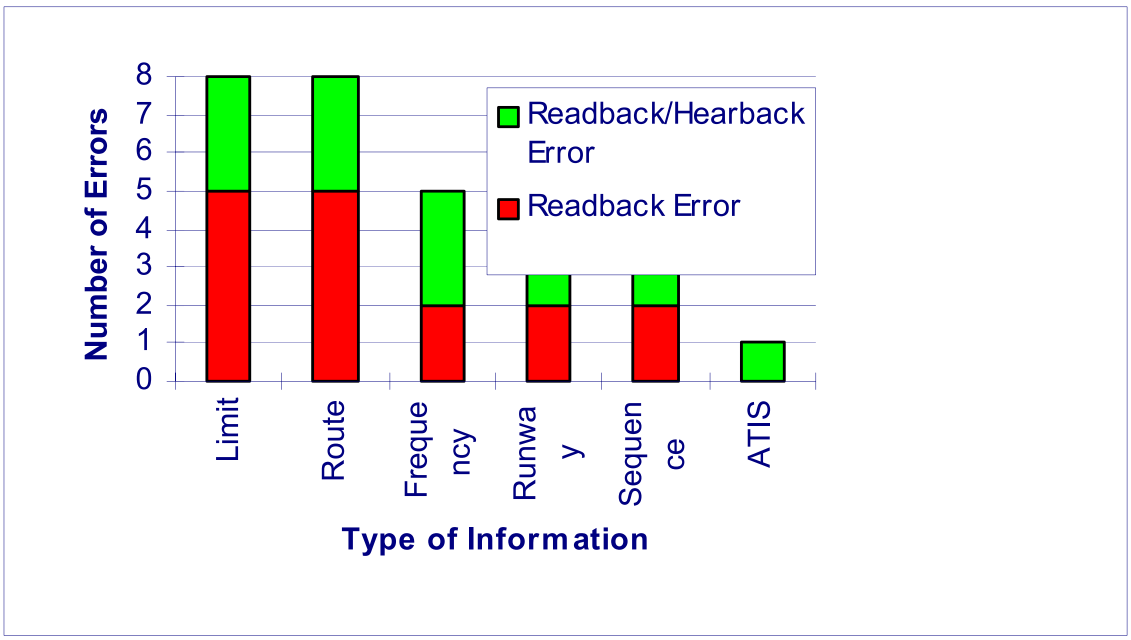

FIGURE 6. NUMBER OF READBACK AND HEARBACK ERRORS FOR EACH TYPE OF INFORMATION.

Four errors, or 14 percent, may have been caused by interference of other information contained in the instruction. For example, when the controller advised "Expect 27L" in the same instruction, the instruction to hold short of runway 27R was read back as hold-short of 27L. Similarly, when the controller advised of traffic on the "outer" and, in the same instructions, asked the pilot to join the inner taxiway, the pilot read back that he had to join the outer instead of the inner taxiway. After being told to "turn left on Quebec and hold short of Quebec 4," a pilot read the limit back as Quebec and omitted the turn left instructions. When the taxiway was November and the ATIS was Quebec, the pilot read the ATIS back as November and omitted the taxiway.

In one case, the controller was apparently very busy, as shown by an apology for the wait, and might have spoken too quickly. Another error, concerning the sequence, occurred after multiple changes of the instruction by the controller, increasing the cognitive workload of the pilot and, presumably, also an indication of high controller workload.

In another case, a pilot of a Japanese aircraft with a very heavy foreign accent read back "pass behind the DC 10 exiting the runway. He will turn right" as "we will turn right." His readback of the controller's correction was almost unintelligible.

Other errors involved the confusion of left and right, inner and outer, V and W, etc., but none occurred more than once.

In summary, two emerging patterns associated with readback errors are interference from other pieces of information in the instruction and the complexity of the instructions to be read back. Fluency in English and controller speech rate were a factor in at least one readback error each.

5.4 CALLSIGN CONFUSIONS

5.4.1 Overview

There were 118 cases of callsign (CS) discrepancies in the 23,224 transmissions, that is, exchanges in which pilots and controllers did not use the same callsign. Figure 7 shows that in the majority of these transmissions, the controller appears to be using the wrong callsign (90).[5]

Fifty-two of the confusions by controllers were resolved. Forty-five of these confusions were corrected by the pilot of the intended (but incorrectly named) aircraft in the acknowledgment or with a question, sometimes only after two or three ATC calls that remained without response. In two cases, the named (but not intended) aircraft alerted the controller, one with a question and the other with the statement "We already did that." In five cases, the controllers corrected the confusion themselves, three times in a subsequent transmission, once after the pilot responded, and once after nobody responded to the wrong callsign. Fourteen of the corrections were not explicitly acknowledged.

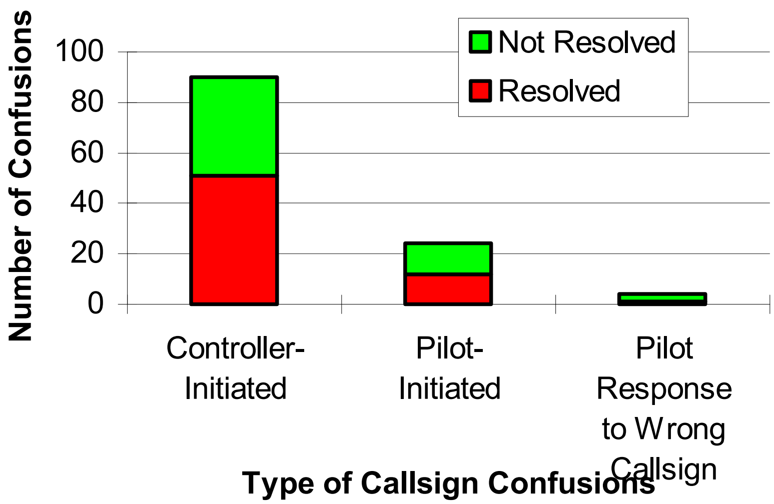

FIGURE 7. NUMBER OF CALLSIGN CONFUSIONS FOR EACH TYPE OF CONFUSION.

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5. As determined by the subject matter experts (one controller and three pilots) who analyzed the audiotapes. Decisions as to who was using the incorrect callsign were a judgment call, because the analysts did not have the flight strips.

Of the 38 controller-induced callsign discrepancies that remained unresolved, 13 were answered by the presumably intended, but incorrectly named aircraft without correcting the callsign. In at least two cases, the pilot had previously corrected the controller, but the controller continued to use the discrepant callsign. In one case, a third aircraft responded, which led to an exchange with multiple callsign confusions (see below). The remaining 22 confusions appeared to remain unanswered.

Of the 28 pilot-initiated callsign confusions, 24 occurred in transmissions and 4 were responses to wrong callsign. Half of the callsigns in transmissions were corrected by the controller, sometimes with a question. Except for two, these corrections were acknowledged.

Only one of the four responses to the wrong callsign was successfully corrected by the controller. For another erroneously accepted transmission including a frequency change, the controller tried to correct the confusion, but the aircraft had already switched to the new frequency.

5.4.2 Callsign Confusions By Controllers

Of the 90 callsign confusions by controllers, 23 were part of ten exchanges involving multiple callsign confusions. Because these exchanges effectively illustrate the load imposed by callsign confusions on the ATC system, even when they remain without serious consequences, some of them will be discussed in detail below.

In one of these exchanges, involving three aircraft from the same carrier, the controller asks Aircarrier 1407 for a repeat after a hard-to-understand transmission from 1406 (first confusion). Now 146 mistakenly tries to respond (this was one of the five responses to the wrong callsign by pilots), but 1406 steps on, giving a correct callsign and repeating its request for a ramp transition. The controller responds with a follow-up question ("taxi or tow"), using 146 (second confusion). Aircarrier 1406 responds "taxi" without giving its callsign. The controller gives taxi instructions "by Lima as requested," and continues to use 146 (third callsign error). Now 146 comes on the frequency with "(ATC facility), we have Zulu." The controller asks for a repeat, and 146 responds with the full callsign and location, indicating "Zulu for (facility)." The controller responds with the correct callsign 146, ATC facility identification, and taxi instructions. They are read back correctly, although without callsign. No mention of the confusion was made by any of the parties involved. Contributing factors to the confusions in this exchange were sound quality of the first transmission, similarity between the callsign 1406 and 146 of the same carrier, response to wrong callsign without correction (first by 146, then by 1406), and omission of callsign and readback by 1406.

In another multiple exchange taxing the ATC system, the controller calls Aircarrier 69 Alpha first by its correct name, but then, when there is no response, switches to (same) Aircarrier 69 Bravo for the next call. After two calls without response, (same) Aircarrier 341 asks whether the call is for 341. The controller answers in the negative and gives up after two additional attempts to contact 69 Bravo.

The vast majority of callsign confusions involve a difference of only one number or one letter. Only few differ in the name of the carrier; in those cases, usually the numbers are identical (Aircarrier A 546 instead of Aircarrier B 546). Numbers are either dropped (146 for 1406), added (16-24 for 6-24), substituted (7-98 for 7-28), or transposed (16-17 for 16-71). Sometimes, an aircraft with a similar callsign was indeed on the same frequency. In two cases, the pilot was hard to understand. In one case, the pilot called up and said "Aircarrier 1444 Echo *five*," which may have induced the controller to call the aircraft "Aircarrier 144*5*." In another case, a controller calls "Aircarrier 757 on the 18 Bridge" for an urgent hold-short instruction, when addressing Aircarrier 1720. Apparently, the controller used location and aircraft type for rapid identification instead of the correct callsign. Incidentally, the aircraft read back "Go to India" instead of "Hold short of India for traffic" without correction by the controller. The outcome of this possible misunderstanding is not known.

5.4.3 Callsign Confusions By Pilots

The 28 callsign confusions by pilots did not differ very much from the ones made by controllers. Again, the majority involve changes in the numbers contained in the callsign. A few are due to the pilot giving up correcting a controller using a similar, but incorrect callsign and adopting it themselves.[6]

In only one case did a pilot respond to a wrong callsign that was similar. In the remaining three responses to the wrong callsign, the wrong callsign was quite different from the correct one. In one case, Aircarrier A 1310 responded to a call for Aircarrier B 707, in another Aircarrier C 1582 responded to Aircarrier D 978. Possibly, the most potent factor enticing a pilot to respond to an instruction for other aircraft is its similarity to the instructions the pilot is waiting for, rather than just a similar callsign. Although none of the three responses to wrong aircraft that remained undetected appears to have had consequences, the potential for an incident is evident.

5.5 CONCEPTUAL ERRORS

The 29 conceptual errors *identified*[7] in this analysis are not *communication* errors per se, but rather errors in cognition, such as when a controller sends a pilot to the wrong runway or a pilot dials in the ground control frequency when he or she wants to talk to the ramp. They are included in this discussion because they also affect the efficiency of the ATC system.

6. An alternative explanation is that the controller may have been right after all.
7. Only errors that were either corrected in a subsequent communication or apparent from the context could be identified.

5.5.1 Conceptual Errors By Controllers

Figure 8 shows the distribution of the nine conceptual errors made by controllers. Three taxi instructions sent the aircraft to the wrong destination, e.g., a gate instead of the cargo ramp, the wrong ramp spot, or, more seriously, to runway "32 left" instead of "right." Two instructions gave the wrong sequence ("after Aircarrier A 75" instead of "Aircarrier B 737"), and two more the wrong taxi direction (east instead of west, or left instead of right). For the last two errors, controllers pointed out traffic from the wrong direction and issued the wrong ATIS as current. Except for the ATIS, all errors were corrected during readback or hearback and acknowledged by the other party.

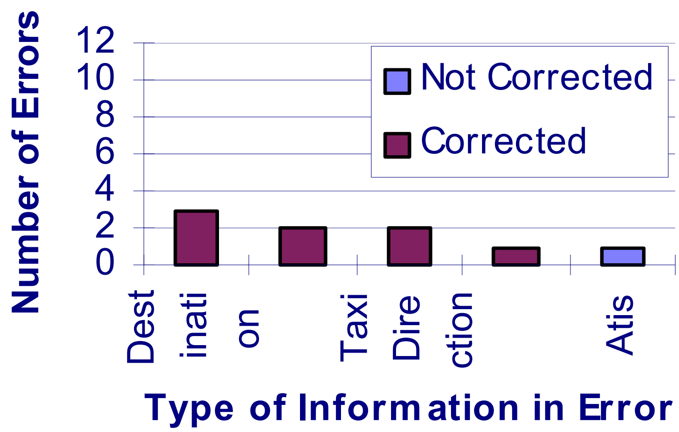

FIGURE 8. NUMBER OF CONCEPTUAL ERRORS BY CONTROLLERS FOR EACH TYPE OF INFORMATION.

5.5.2 Conceptual Errors By Pilots

Figure 9 shows the distribution of the 20 conceptual errors made by pilots. Twelve of these involved dialing in the wrong frequency, i.e., talking to ground control when trying to reach the ramp (seven cases), arrival ground (three cases), or clearance delivery (two cases). Nine of these erroneous contacts were pointed out by the controller, but for two ground control did respond with an instruction. One remained without response. In five instances, a pilot gave a wrong location (the wrong bridge, ramp, taxiway or runway). All of these were corrected, two by the controller, three by the pilot after the controller's response. In two cases, pilots inadvertently keyed the mike while speaking to each other. One of these transmissions may have been mistaken for an acknowledgment by the controller, the other was resolved with a question from the controller. In one last case, a pilot indicated the current ATIS as "Yankee" instead of "Sierra" and was corrected by the controller.

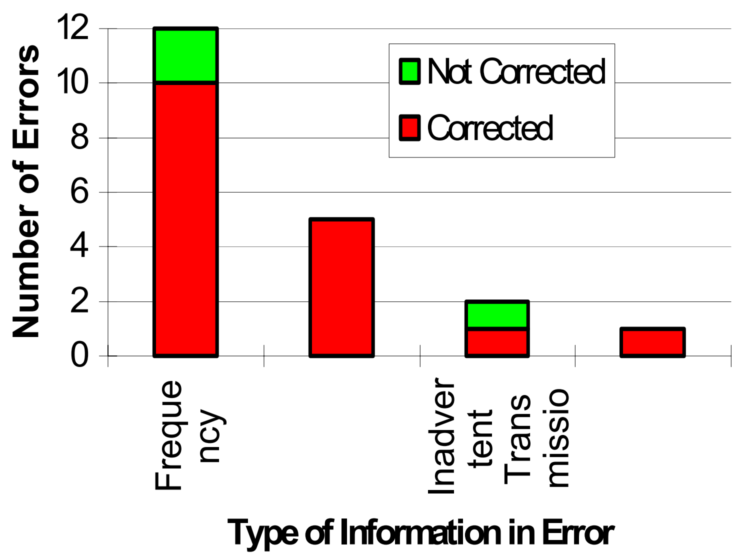

FIGURE 9. NUMBER OF CONCEPTUAL ERRORS BY PILOTS FOR EACH TYPE OF INFORMATION.

5.6 COMMUNICATION PROBLEMS AND TRANSMISSION DENSITY

The incidence of communication problems seems to be unaffected by the frequency congestion during the period sampled. No or negligible correlations were found between conceptual and callsign errors and transmission density or between readback errors and instruction density at a facility (Pearson $r_{xy}<|.26|$). Interestingly, when the readback error rate was calculated as a percentage of the overall transmission rate instead of only the instruction rate and correlated to the transmission density, the correlation was somewhat higher (Pearson $r_{xy}=.40$, that is, 16 percent of the increase in readback errors was associated with an increase in transmission density).

6. SUMMARY AND COMPARISON WITH PREVIOUS STUDIES

A first finding was that while the majority of instructions in the ground control environment contained three or fewer pieces of information, over a third of the instructions contained four or more pieces of information to remember. This finding is important considering the effect of complexity of the instructions on how pilots respond to the instructions and on the incidence of readback errors and requests to hear the instructions again (see below).

Ideally, a pilot would read the instructions back in full, so that the controller can verify whether the instructions have been understood correctly. The data show that the incidence of full readbacks dropped significantly with increasing complexity, while the incidence of partial readbacks increased. Overall, fewer than a third of the instructions were read back in full. This needs to be kept in mind when looking at the nevertheless impressively low readback error rate of fewer than one percent.

One-word acknowledgments also decreased with increasing complexity. Requests to repeat all or part of the information, although overall low (fewer than one percent), increased from half a percent at complexity level one to over three and a half percent at complexity level eight.

The 28 readback errors were highly correlated to the complexity of the instructions, ranging from fewer than one percent up to complexity level three to over two percent at complexity level seven. Besides complexity, contributing factors to erroneous readbacks were interference from other information in the same instructions and, in one case each, fluency in English and controller speech rate. Twelve of the readback errors remained unresolved, with consequences unknown. With eight errors each, the most frequently misunderstood information was on taxi limits and routes.

Compared to the en-route environment with fewer than five percent of all instructions containing more than four pieces of information (Cardosi 1993), instructions from tower-ground (over 35%) and tower-local control (31%, Cardosi 1994) were considerably more complex. Also, the transmission density in the three environments varied considerably, going from 1.8 transmissions per minute in the en-route environment to 3.9 and 8 transmissions per minute at local and ground control, respectively. Pilots' perception of how busy a controller and how congested a communication frequency is may thus be a factor in the fact that instructions were most likely read back in the en-route environment and least likely in the ground environment.

Similar, however, was the incidence of readback error rates and of requests to repeat the information in the three environments, all below one percent. And for all three environments, the errors and requests for repetition increased with increasing complexity of the instructions. This finding has also been confirmed experimentally in Bürki-Cohen, 1995 a and b, and Morrow and Rodvold, 1993.

Morrow, Lee, and Rodvold (1993) documented a similarly low readback error rate for the TRACON environment, analyzing 42 hours of communications with over 6 transmissions per minute, although only half of these errors were corrected by controllers. In the en-route environment (Cardosi, 1993), only 11 percent of readback errors were not corrected by the controller (hearback error). In the tower environment, however, the hearback-error rate rose to 37 for local and 40 percent for ground control. It appears that hearback errors increase with increasing transmission density, given the considerably higher transmission densities in the tower and TRACON compared to the en-route environment with fewest hearback errors.

Other communication problems examined in this study include aircraft callsign discrepancies and conceptual errors. Both types of problems may occur in any type of transmission, not only instructions and responses to instructions. Again, the incidence was lower than one percent, although conceptual errors may not always be apparent from the audiotapes. The few conceptual errors apparent from the audiotapes were made mainly by pilots; most involved dialing in the wrong frequency.

Callsign discrepancies appeared to be initiated mainly by controllers. Most of these were either explicitly or implicitly resolved, or the instructions remained unanswered. Of the callsign confusions in pilot transmissions, half were corrected, usually by controllers. Most confusions involved only one number or one letter, rarely the aircarrier name. Some were induced by a similar callsign on the same frequency. Although none of the discrepant callsign uses appeared to represent a safety problem *per se*, many resulted in lengthy exchanges involving multiple callsign confusions, tying up the communication frequency. More problematic, from a safety standpoint, are the fortunately only four responses to a wrong callsign by pilots, of which three remained undetected--with unknown outcome. Interestingly, similarity between the *callsigns* of the intended and the responding aircraft appeared to be a factor in only one of these cases, suggesting that it was the match between the expected and the issued *instructions* that enticed the wrong pilots to respond. Cardosi (1993, 1994) reported similar incidences of callsign discrepancies for the en-route and local control environments.

7. RECOMMENDATIONS

A readback error rate of fewer than one percent is a tribute to the pilots and controllers operating in the National Airspace System. Nevertheless, the readback errors encountered were serious and had the potential for grave consequences, especially the 50 percent errors that were not corrected or for which the correction was not acknowledged. Similarly, callsign confusions, responses to wrong callsign, and conceptual errors were relatively few compared to opportunity, but, even in the best of cases, impose a load on the communication frequency. The following recommendations to further improve ATC communications and thus the margin of safety in the ground-control environment arise from this investigation:

1. Controllers should keep instructions short. Lengthy instructions also increase the possibility of interference from similar pieces of information within the same transmission, such as when a controller designates one side of a runway for departure while asking to hold short of the other side of the same runway. Furthermore, the shorter an instruction, the more likely will it be read back by the pilot.

2. Controllers should listen to what a pilot reads back, especially regarding hold-short and taxi instructions and frequencies. More emphasis should be given to hearback during controller training (ASRS Callback, 1992).

3. Controllers should try to speak slowly *especially* when they are under pressure and don't have time to repeat information.

4. When talking to foreign pilots, controllers should take into account the potential for phraseology differences and reduced English language proficiency. An example of a phraseology difference is that a foreign pilot who is instructed to "taxi into position" may *hold short of* the runway, instead of taxiing *onto* the runway. The FAA should compile a list of such differences to be distributed to controllers *and* pilots, especially those flying internationally. Foreign pilots may also be used to a different definition of flight levels as well as encounter conversion problems (e.g., millibars into inches of mercury). Moreover, repeating numbers in grouped format, i.e. "seven-teen," instead of sequential format, "one seven," as recently authorized for emphasis of altitudes (FAA, 1992), may backfire with foreign pilots who group numbers differently in their own language (e.g., in French, "seven-teen" is said as "ten-seven").[8] A last recommendation is to speak "*staccato,*" that is, to break the instruction up into its component words by inserting tiny pauses. Recognizing where one word ends and the next begins is notoriously difficult for any inexperienced listener of a foreign language.

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8. We are currently investigating the effects of grouping numbers on pilot recall and have so far found that the costs of grouping may outweigh the benefits also for pilots whose first language is English (Bürki-Cohen, 1995 a, b).

5. Pilots should ask when they are not sure about a piece of information. Simply reading the instructions back may not be enough, because controllers are often busy with other tasks during readback. But even if pilots are sure that they have heard and remembered correctly, they should at least read back hold-short instructions and frequency changes.

6. Whenever possible, controllers should point out similar callsigns on the same communication frequency. All instructions and readbacks should include the full callsign.

7. Both controllers, when listening to readbacks, and pilots, when taking instructions, should be aware of how their expectations may affect what they hear. Pilots expecting certain instructions must wait for complete aircraft identification before taking action on the instructions.

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