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An Analysis of Tower (Local) Controller - Pilot Voice Communications

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The purposes of this analysis were to examine current pilot-controller communication practices in the terminal environment. Forty-nine hours of voice tapes from local positions in ten Air Traffic Control Towers (ATCTs) were examined. There were 8,444 controller-to-pilot messages (e.g., clearances to takeoff or land, instructions to hold short or change radio frequencies, etc.) examined in this study.

The complexity of the controller's message (i.e., the number of pieces of information) was examined and the number of erroneous readbacks and pilot requests for repeats were analyzed as a function of message complexity. Pilot acknowledgements were also analyzed; the numbers of full and partial readbacks, and acknowledgements only (i.e., "roger") were tallied.

Fewer than one percent of the messages resulted in communications errors. Among the error factors examined were: complexity of the message, type of acknowledgement, use of call sign in the acknowledgement, type of information in error, and whether or not the controller responded to the readback error. Instances in which the controller contacted the aircraft with one call sign and the pilot acknowledged the transmission with another call sign were also examined. The report concludes with recommendations to further reduce the probability of communication errors.

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PREFACE

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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 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .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 yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 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 milliliters (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

INCHES	0		1		2			3		4			5		6			7			8		9			10
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25 25.40

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°

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

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EXECUTIVE SUMMARY

The sheer volume of communications between pilots and air traffic controllers makes human error inevitable. The opportunity for miscommunications is constant and the consequences range from annoying to potentially dangerous. At the very least, miscommunications result in increased frequency congestion and increased controller workload, as more communications are necessary to correct the problem. Depending on the nature of the error, miscommunications have the potential of narrowing the margin of safety to an unacceptable level. Information obtained by sampling controller-pilot voice communications is useful in a variety of ways. Not only does it give insights into the frequency of occurrence of specific practices that are known to affect the efficiency of communications, but it also allows us to address specific questions that need to be answered to develop and evaluate new systems and procedures.

The purposes of this tape analysis were to examine current pilot-controller communication practices in the local control (tower) environment and to analyze the communication errors in detail. Forty-nine hours of voice tapes from ten Air Traffic Control Towers (ATCTs) were examined. There were 11,234 controller-to-pilot transmissions in this sample. This included 8,444 messages of substance (e.g., clearance to takeoff or land, instructions to hold short or change radio frequencies, etc.) and 2,790 requests for information, salutations, etc.

The majority of these controller messages contained one, two, or three pieces of information and were acknowledged with a full or partial readback. Less than one percent of the pilots' readbacks contained an error. There were only seven instances in which a controller did not notice the error in the pilot's readback. This represents 37% of the readback errors and less than one-tenth of one percent of the total number of controller messages.

The single most common type of readback error involved confusing the right and left runways of the same number. Such errors accounted for 21% of the 19 readback errors found in the analysis. An additional 32% of the readback errors were due to various types of errors associated with taxi instructions.

There were also 81 instances (.9% of the messages) in which the pilots responded to controller transmissions with different call signs than the controllers used. What was surprising about these incidents was that less than half of these call sign discrepancies were corrected.

There were 78 instances (less than 1% of the messages) of pilots requesting that a controller repeat all or part of the transmission. The rate of miscommunications (i.e., readback errors and pilot requests for repeats) for messages containing one to five pieces of information was less than 1% at each level

of complexity. The rate for messages containing six and seven elements was 1.4% and 1.3%, respectively.

Several factors of interest were examined as coincident to the communication errors. However, the only factor that was found to be associated with communication errors was similar call signs on the same frequency. The absence of evidence of the significance of other factors was probably due, at least in part, to the small number of errors found and examined.

One of the most striking findings of this analysis was how few communication errors were found. A readback error rate of less than one percent is a tribute to the pilots and controllers operating in the National Airspace System. Still, pilots and controllers need to be aware that catching readback errors is a difficult task, particularly when combined with other duties that need to be performed simultaneously. Pilots need to be encouraged to ask for clarification, rather than expect the controller to catch readback errors. Pilots should also be diligent about using their full call signs to acknowledge controller transmissions. Controllers should listen for the call sign, as well as the content, of the pilot's readback. Controllers should also continue to warn pilots when there are similar call signs on the same frequency, whenever possible. Such practices and increased awareness can further reduce the probability of communication problems and further increase the margin of safety.

1. INTRODUCTION

Communication problems between pilots and controllers are often cited as a major factor that affects system performance. Many operational errors, pilot deviations, accident/incident reports, and Aviation Safety Reporting System (ASRS) reports either directly involve, or reference, a breakdown in the verbal transfer of information. While some work has been done to help define the nature and causes of communication errors, much more work is needed. The sheer volume of Air Traffic Control (ATC) communications makes human error inevitable. The opportunity for miscommunications is constant and the consequences can range from annoying to dangerous. At the very least, miscommunications result in increased frequency congestion and increased controller workload, as more communications are necessary to correct the problem. Depending on the nature of the error, miscommunications have the potential of narrowing the margin of safety to an unacceptable level.

It is well-known that pilot-controller communications are not rigidly uniform. The exact format and wording of messages relayed by controllers and pilots vary as a complex function of the airspace environment, controller and pilot workload, and individual style. For example, while pilots are encouraged (in all but the busiest ATC environments) to readback key information (e.g., altitude) as a matter of good communication practice, it is not uncommon for pilots to acknowledge a transmission with the reply "*roger*" or "*good day*", instead of a readback of even part of the controller's message. While this practice deprives the controller of the opportunity to catch a readback error, it is often necessary on congested frequencies during extremely busy traffic periods. Exactly how often this occurs had not yet been studied in the terminal environment, nor was it known how often these practices contribute to communication errors. Similarly, it is common for a pilot to request the controller to repeat a message ("*say again*"). However, the percentage of all transmissions that need to be repeated had never been examined for tower communications. This additional transaction adds to a controller's workload and to frequency congestion. Information obtained by sampling pilot-controller voice communications is useful in a variety of ways. Not only does it give insights into the frequency of occurrence of specific practices that are known to affect the efficiency of communications, but it also allows us to address specific questions that need to be answered to develop and evaluate new software and procedures. For example, knowing the percentage of clearances that need to be repeated by controllers would be useful in the evaluation of the efficiency of sending ATC messages via data-link.

Previous work in ATC voice tape analysis has focussed on TRACON and on en route communications. Morrow, Lee, and Rodvold (1993), examined TRACON communications and found a readback error rate of less than one percent with only half of these errors "repaired" by controllers. Partial or missing readbacks occurred in 3-13% of acknowledgements (depending on the individual TRACON sampled) with partial readbacks being more common for longer ATC messages. A study of en route communications also found an error rate of less than one percent (Cardosi, 1993). Most of these errors involved instances in which pilots responded to controller transmissions with different call signs than the controller had used, or lengthy controller transmissions that resulted in erroneous pilot readbacks. There was a 1-3% miscommunication rate (i.e., of readback errors and requests for repeats) for clearances containing one to four pieces of information and a 8% rate for transmissions containing five or more elements. Although clearances containing five or more pieces of information constituted only 4% of the messages examined, it accounted for 26% of the readback errors found in the sample.

The purpose of this tape analysis were to examine current pilot-controller communication practices in the local control (tower) environment and to analyze the communication errors in detail. While the current analysis focussed on the tower local control position, future analyses will examine pilot-controller communications with ground control and TRACON positions. These analyses document the incidence (i.e., on what percentage of the communications is this noted?) and consequences of the following practices:

- pilots acknowledging controller transmissions with complete readbacks;
- pilots acknowledging controller transmissions with incomplete readbacks;
- pilots responding to controller transmissions with only an acknowledgement (i.e., "roger");
- requests for repeat of controller transmissions;
- controllers failing to detect pilot readback errors; and
- controllers relaying multiple instructions in a single transmission.

An analysis of ASRS reports is currently being conducted to provide a larger data base suitable for an in-depth study of miscommunications that is not practical with tape analysis, alone. While the tape analysis can address the frequency with which miscommunications occur, it cannot provide a suitable data base for extensive errors analysis, since the frequency of errors is small relative to the total number of transmissions.

2. METHOD

Forty-eight hours of voice tapes from local control positions at ten different ATC towers were analyzed. Depending on the quality of the tapes received, between three and six hours from each of the following facilities were included in the analysis: Albuquerque, Atlanta, Boston, Dulles (Washington, DC), Los Angeles, Miami, Philadelphia, Phoenix, Pittsburgh, and Seattle.[1] These facilities were selected to sample different geographical locations (i.e., east coast, west coast, central), different workload levels, and different traffic mixes (e.g., inclusion of towers with a relatively high proportion of foreign carriers). Twenty-four hours of tape analyzed were from periods of high workload (as defined by the facility) and 24 hours were from periods of moderate workload. Towers with more than one local position (e.g., departure and arrival) were asked to sample the different positions. The purpose of these selections was to achieve a representative sample of different local operations (excluding the very low workload periods, e.g., middle of the night, which would yield little interesting data).

The tapes were analyzed by three subject matter experts (one former controller and two pilots). All communication errors were transcribed and set aside for separate analysis.

Part of the analysis examined miscommunications. This included communication errors and pilots' requests for repeat of part or all of the transmission. Miscommunications were examined as a function of the complexity of the controller's message. Message complexity was measured in terms of the number of separate elements contained in a single transmission. Each word, or set of words, the controller said that contained a new piece of information to the pilot, and was critical to the understanding of the message, was considered to be an element. An element could also be considered as an opportunity for error. For example, "American 123, cleared to land runway two niner" was considered two elements. However, "American 123 cleared to land runway two niner **left**" was counted as three elements, since there is an opportunity to mistakenly land on two niner right. Usually, the counting is straightforward. Changes in altitude or heading are each considered to be one element as are individual taxiways, runway numbers, and left, right. Landing and taxi instructions can contain many elements. Controller transmissions containing clearances to takeoff or land can also include traffic and wind advisories, and taxi instructions. Taxi instructions, even the limited instructions that would be issued on a busy local control frequency can be surprisingly complex. For example, "Taxi down the runway, turn left at Dixie, join November and taxi all the way down to Tango. Hold short of Runway two

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[1] The tapes from each facility were from non-consecutive hours in single hour increments.

seven right as you proceed down November" contains seven pieces of information, but was necessary to get an aircraft with a generator problem back to the gate. Similarly, "Make a right turn on alpha-alpha, left turn on sierra to juliet-juliet and hold short of niner left on Bravo" would be a complex set of instructions (for a single transmission) for a pilot who was unfamiliar with those taxiways.

In this study, only the pieces of information that increase memory load were counted as separate elements. The aircraft call sign was not counted as an element, since it serves only to attract the pilot's attention and is not something that must be remembered as a part of the message. It should be noted that any such counting scheme is necessarily arbitrary. Whether a radio frequency such as "123.45" should be counted as a single element or as four elements (since the one is invariant) is debatable. It is not reasonable to assume that all elements impose the same memory load. It is probably easier to remember to cross a specific taxiway than it is to remember an unfamiliar radio frequency. Yet, for counting purposes, each would be considered as one element. The error analysis does, however, examine errors with respect to the type of information transmitted.

3. ROUTINE COMMUNICATIONS PRACTICES

There were 11,234 controller-to-pilot transmissions on the 48 hours of voice tapes analyzed. This included 8,444 messages of substance (e.g., clearances to takeoff or land, instructions to change radio frequencies or taxi instructions, etc.) that were included in this study. The other 2,790 controller transmissions consisted of requests for information, salutations, controller acknowledgements, etc., and were tallied, but not included in the analysis.

3.1 MESSAGE COMPLEXITY

The length and complexity of messages issued by controllers in a single transmission is often informally cited by pilots as a great source of frustration and potential errors. Indeed, a study of en route communications showed that most of the readback errors involved lengthy controller transmissions (i.e., those that contained more than four pieces of information). Also, Morrow, Lee, and Rodvold (1993) found that incorrect readbacks were more frequent for TRACON communications containing two or more pieces of information than those containing only one. In a part-task simulation study, Morrow (personal communication) found that incorrect readbacks and requests for clarification were more frequent after long messages (i.e., those containing four pieces of information) than for shorter messages.

Table 3-1 shows the distribution of messages by complexity level. The majority of messages contained one, two, or three pieces of information. Twenty percent of the messages contained one element (e.g., cleared for take-off) and 38% of the messages contained two elements (e.g.,position and hold on runway two six). Sixteen percent of the messages contained three elements (e.g., position and hold runway two six right) and almost half (46%) of the messages contained four or more elements. It is important to realize that, in this environment, controllers need to convey a certain amount of information in a single transmission. Consequently, even the simplest of instructions can have three or more elements. For example, "USAir 123, position and hold runway two two left, departing traffic runway one four" has five elements.

TABLE 3-1. PERCENTAGE OF CONTROLLER MESSAGES AS A FUNCTION OF COMPLEXITY

Complexity Level	Percentage of all Messages
1	20%
2	18%
3	16%
4	15%
5	14%
6	7%
7	5%
8	3%
9 or more	2%

3.2 MESSAGE ACKNOWLEDGEMENT

As Table 3-2 shows, the majority of the 8,444 messages were acknowledged with a full or partial readback. Twenty-eight percent of the messages were acknowledged with a full readback and 37% were acknowledged with a partial readback. Twenty-seven percent of the messages were directly acknowledged without a readback (e.g., with a "roger"), while seven percent were acknowledged with only a mike click. Less than one-half of one percent were acknowledged indirectly (e.g., with a question, or a request for a different clearance or additional information) or not acknowledged at all.

TABLE 3-2. PILOT RESPONSES TO ATC MESSAGES

Full Readbacks	28%
Partial Readbacks	37%
Acknowledgement Only	27%
Mike Clicks	7%
No Acknowledgement	<1%
Total	100%

Less than one percent of the readbacks contained an error. This error rate refers to instances in which the pilot read back something (e.g., a runway number, taxiway name or instruction) different from what the controller originally said. These readback errors will be examined in detail in the section on miscommunications.

3.2.1 Use of Call Signs in Readbacks

Pilots gave their complete call sign (i.e., airline name and flight number or last three alphanumerics for a general aviation aircraft) in response to 77% of the messages issued and in 61% of the readbacks containing an error. A partial call sign (e.g., airline name alone or flight number alone) was given in an additional 11% of the readbacks. No call sign was given in 28% of these readback errors. Of the erroneous readbacks given without call signs or with only a partial call sign, 57% were from Part 121 or Part 135 air carriers.

The potential hazards inherent in responding with an incomplete call sign are apparent in the following example. The controller instructs AirCarrier **A** 1471 to contact departure. In fact, the controller intended to instruct AirCarrier **B** 1471 to contact departure. The pilot responded to this instruction with "1471, good day". In this instance, there was no other aircraft on the frequency with the call sign of AirCarrier **A** 1471 and the controller had been communicating with the pilot he intended to contact, so he was easily able to recognize his voice. Still, in the era of hubs (where many aircraft from the same company are operating simultaneously) and similar call signs (such as aircraft from different companies having the same or similar flight numbers), pilots need to be particularly diligent about using their complete call sign.

3.2.2 Message Complexity and Incidence of Readbacks

The longer the controller's transmission, the more likely the pilot was to respond with a full or partial readback, rather than just an acknowledgement. Figure 3-1 shows the percentage of readbacks as a function of message complexity. Controller transmissions that contained one or two pieces of information, such as "Contact ground" or "Fly heading two one zero, contact departure," respectively, were most likely to be responded to with only an acknowledgement. Approximately one-half of the transmissions containing three pieces of information were acknowledged with a readback, and 75% of the longer transmissions were acknowledged with a full or partial readback. (Recall that partial readbacks were more common than full readbacks.) Since taxi instructions are usually complex and contain critical details that can make the difference between an uneventful taxi and a runway incursion, it is prudent that pilots respond with at least a partial readback.

It should be noted that each partial or missing readback presents an opportunity for a communications error, since it does not

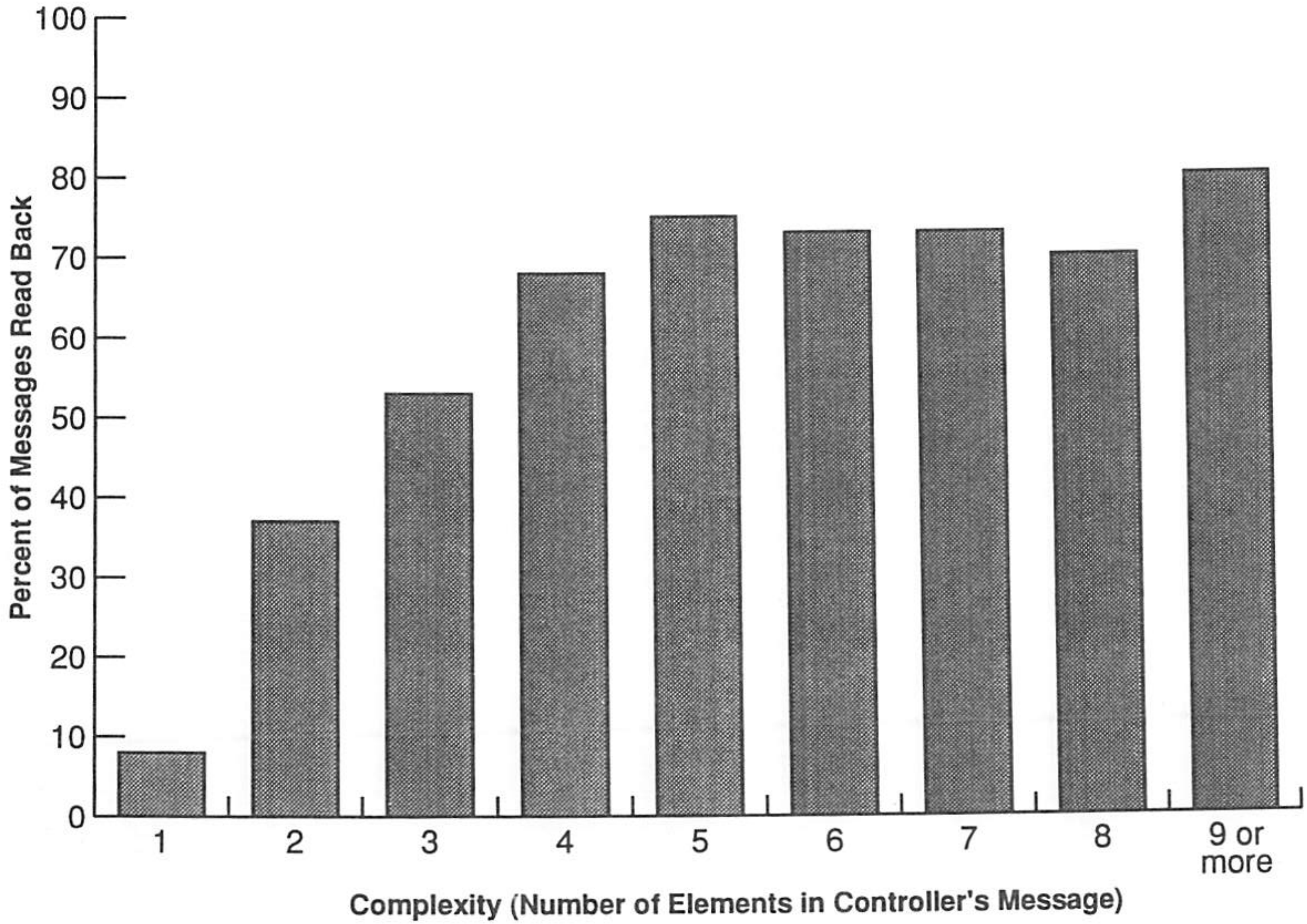

FIGURE 3-1. PERCENT OF MESSAGES READ BACK AS A FUNCTION OF MESSAGE COMPLEXITY

afford the opportunity for a hearback. The consequences of such errors are not likely to appear in this type of tape analysis, since the analysis examined the communications from each sector over the course of an hour and did not follow individual flights from one radio frequency to another (e.g., from tower to ground).

3.3 MISCOMMUNICATIONS

For the purposes of this study, miscommunications consisted of readback errors and pilots' requests for a repeat of all or part of the controller's transmission. Many factors can contribute to miscommunications. One important factor that can lead to both readback errors and to hearback errors is expectation. As humans, we are predisposed to hear what we expect to hear. Voice tape analysis is not a good vehicle for studying the effects of expectation on communication errors. However, the effects of expectation can be quite apparent in some of the errors noted. For example, expectation can lead to readback errors, when what is expected is not what is transmitted. For example, "Maintain minimum approach speed, (pause) change runway, one six **left**, cleared to land" was read back as, "OK, minimum approach speed, uh, cleared to land one six **right**". Note how the expectation to land on one six right was stronger than the "change runway" issued by the controller. It is important to note that, in this instance, the controller did not stress this part of the transmission with a change of voice inflection. There was, however, a significant pause before, and a slight pause after, "change runway".

There are many other important factors the can contribute to miscommunications that cannot be identified in a tape analysis. These factors include pilot and controller workload and distractions. It is useful, however, to examine the important factors that can be studied, such as complexity of controller transmission and type of information in error.

3.3.1 Message Complexity and Readback Errors

Logically, the more information contained in a single transmission, the higher the probability of an error. The more elements in a message, the higher the memory load imposed upon the pilot. There were only 19 communication errors found in the 48 hours of tape analyzed. This represents less than one-fifth of one percent of the 8,444 messages issued. Table 3-3 shows the percent of pilot readbacks and readback errors as a function of the complexity of the controller's original message. Column 1 shows the complexity level of the message, that is, the number of pieces of information contained in the transmission. Column 2 shows the percentage of these transmissions that were responded to with a full or partial readback (as opposed to an acknowledgement only). This was computed by dividing the number of pilot readbacks at that level by the number of controller transmissions at that level. Column 3 shows the number of readback errors at each complexity level. Column 4 shows the percentage of readback errors at each complexity level. These percentages were obtained by dividing the number of errors made with messages at that complexity level by the total number of readbacks of messages at that level. For example, there were four readback errors at complexity level five and 1,176 messages that contained five elements. This yields a readback error rate of .003 or .3%. The overall error rate is quite low and is less than one percent at all complexity levels, except level eight. Messages containing eight pieces of information had a readback error rate of almost two percent. Still, there is no reason to suspect that there is anything unusual about messages with eight pieces of information.

TABLE 3-3. PERCENTAGE OF READBACKS AND READBACK ERRORS AS A FUNCTION OF MESSAGE COMPLEXITY

Complexity Level	Percentage of Full and Partial Readbacks	Number of Readback Errors	Percentage of Readback Errors
1	8%	0	0%
2	37%	2	.3%
3	53%	1	.1%
4	68%	4	.4%
5	75%	4	.3%
6	73%	1	.2%
7	73%	3	.8%
8	70%	4	1.8%
9 or more	80%	0	0%

The complexity of the controller's transmission seems to have had little effect on the readback error rate in these communications. This finding stands in sharp contrast to the results of a study of the en route environment. An analysis of voice tapes from Air Route Traffic Control Centers (ARTCCs) showed that the readback error rate increased significantly with the complexity of the controller's transmission (Cardosi, 1993). However, for several reasons, the number of pieces of information in the local transmissions studied cannot predict the pilot's memory load imposed by the transmission as well as it does in the en route environment. First, many of the lengthy transmissions in a terminal environment are predictable, based on standard procedures (e.g., SIDSs and STARs) and the information available on the ATIS and via the partyline (i.e., transmissions between the controller and other aircraft); this is not as true en route. (Also, since pilots expect calls from controllers in the terminal environment more so than in the en route environment, they may be more attentive and ready to respond.) Second, the degree to which the pilot is familiar with the airport and local procedures will affect the memory load imposed by the transmission. A pilot who is accustomed to receiving a particular set of instructions at a particular time (e.g., approach, arrival, or taxi instructions), is much less likely to make an error in the readback or execution of those instructions, even though the transmission may be lengthy, than a pilot who receives a lengthy and unexpected transmission.[2] Third, this analysis, by default, counted each piece of information (e.g., each taxiway) as equal and independent. In reality, many of these pieces of information could be logically grouped by the pilot and would not impose the same memory load as the same number of unrelated pieces of information. Unfortunately, the actual memory load imposed by a given transmission cannot be evaluated in such a tape analysis, since it depends on factors such as pilot expectations, the pilot's familiarity with the airport, and readiness to write down a clearance.

Support for the fact that something other than the complexity of the controller's transmission is contributing to the readback errors, comes from the lack of readback errors for transmissions that contained nine or more elements. Recall that 80% of these transmissions were responded to with a full or partial readback. It is unlikely that these transmissions came as a surprise to the pilot and, by chance, did not lead to any readback errors. It is more likely that the pilots were prepared, in one way or another, for these lengthy transmissions. It is important to note that transmissions where the controller warned the pilot of its length (as in asking if the pilot was "ready to copy") were not analyzed separately, nor were they excluded from the error analysis.[3]

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[2] As previously noted, however, expectation is a double-edged sword. Knowing what message to expect can help the pilot to hear and remember the message as long as the expected message is what was transmitted.

[3] The number of readback errors was so small that excluding the small number of lengthy, but "prompted" transmissions would have had little effect on the error rate.

3.3.2 Readback Errors and Type of Information

Table 3-4 shows the distribution of readback errors as a function of the type of information in error.[4] The most common type of readback error involved various errors regarding taxi instructions. This accounted for 37% of the readback errors found in this study. These taxi instructions contained an average of six elements per transmission. Confusions of right and left runways of the same number accounted for 22% of the 19 readback errors found in the analysis, and errors involving altitude accounted for 16% of the errors.

TABLE 3-4. DISTRIBUTION OF READBACK ERRORS BY TYPE OF INFORMATION

Type of Information in Readback Error	Number of Readback Errors	Proportion of Readback Errors
Taxi Instructions	7	37%
Right and Left of Same Runway Number	5	26%
Altitude	3	16%
Heading	2	10%
Transponder Code	1	5%
Other	1	5%

A common type of error involves transposing numbers in a message. In the following example, the pilot confused the numbers in the runway with the heading. "Turn right, heading **one three five**, Runway **one two**, cleared for takeoff, traffic arriving niner right will hold short of the intersection" was read back as, "Cleared for takeoff, heading **one two zero**". The controller missed this particular readback error and later had to correct the pilot's course. In this instance, the unconventional sequence of instructions and information (i.e., heading, runway number and cleared for take-off, rather than cleared for take off, runway number and heading) may also have contributed to the readback and hearback errors.

In addition to these readback errors, there was one instance of the wrong aircraft accepting a clearance to land intended for another aircraft. Contributing to this error (both on the pilot's and controller's part) were the physical proximity of the two aircraft and the similar call signs. Both aircraft were on

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[4] In addition to the readback errors shown in this table, there was another readback error that went unchallenged by the controller. In this instance, an aircraft was instructed to cross Runway 29 Left. The pilot read back that he would cross Runway 29 Right. Since this aircraft had landed on 29 Right (the very runway he was proposing to cross), this error was regarded as a "misspeak" and was not tallied as a readback or a hearback error.

final approach for the same runway and the call signs of the two aircraft were flights two-eighteen and ten-eighteen of the same airline. The clearance to land was issued to (and intended for) the aircraft closer to the runway, but was accepted by the other aircraft. The closer aircraft didn't acknowledge the clearance, (or the transmission was blocked) and landed without incident. The aircraft that accepted the clearance later reported being on final approach.

3.3.3 Hearback Errors

There were only seven instances in which the controllers did not notice an error in the pilot's readback. This represented 37% of the 19 readback errors and less than one-tenth of one percent of the total number of messages. Most of these hearback errors followed readback errors of taxi instructions. Recall that the communications analyzed in this study were from local control positions and not ground control. These hearback errors did not occur while the controller was performing dual duties, since the tapes were from moderate and high workload periods and times in which these positions were not likely to be combined. In fact, three of the seven controller transmissions that resulted in a hearback error conclude with the instruction to contact the ground control frequency. However, since the number of errors is so small, and since the exact circumstances of the errors (such as the controller's duties at the time of the error) are unknown, a detailed analysis of these hearback errors is not possible. As with the previous study of en route communication, there were too few readback and hearback errors found in this study to contribute to our understanding of hearback errors.

3.3.4 Message Complexity and Pilot Requests for Repeats

Pilots who are unsure of all or part of their clearance should request a repeat of the part in question. Some pilots will readback *what they thought they heard* with the hopes that they are correct and, if not, then the controller will catch their error. In this sense, every "say again" and request for a repeat of part of the transmission is a readback and hearback error averted. Still, such requests, while necessary, add to the controller's workload as additional transmissions are needed to correct the problem. There were 78 instances (less than 1% of the messages) of pilots requesting that a controller repeat all or part of the transmission. Table 3-5 shows the percentage of messages followed by a pilot's request to repeat all or part of the transmission. The results are similar to those for pilot readback errors. Generally, the rate of pilot requests for repeats increases as message complexity increases, but never exceeds 2%, even for the most complex transmissions.

TABLE 3-5. PERCENTAGE OF TRANSMISSIONS REQUIRING FULL OR PARTIAL REPEAT DUE TO PILOT REQUEST

Number of Elements in Controller Transmission	1	2	3	4	5	6	7	8	9 or more
% of Transmissions Requiring Full or Partial Repeat due to Pilot Request	.6%	.6%	.8%	.9%	.9%	1.3%	1.9%	1.3%	1%

3.3.5 Call Sign Discrepancies

There were 81 instances (approximately one percent of the messages) in which a pilot responded to a transmission with a call sign that was different than the one used by the controller. In only one of these instances was there evidence that the other call sign was actually another aircraft on the same frequency. (This instance, in which one aircraft accepted a clearance to land intended for another aircraft, was described under the section on readback errors.) Table 3-6 shows the distribution of these call sign discrepancies. Twenty-eight percent of these transmissions contained clearances to land or takeoff, and 20% of these transmissions contained instructions to change frequencies. What was most surprising about all of these incidents was that only 48% of these call sign discrepancies were corrected. Only 26% of the call sign discrepancies that were corrected were done so with direct pilot questions or statements (e.g., "Was that for Airline 123?"), another three percent were corrected by direct controller questions or statements. The rest of the discrepancies were indirectly corrected by either the pilot or controller changing the call sign on a subsequent transmission to conform to what the other party used. In the majority (87%) of the call sign discrepancies that were corrected in this way, the controller changed the call sign used to conform to what the pilot had used. Approximately one-half (52%) of the all of call sign discrepancies went uncorrected as the controller continued to call the aircraft with one call sign and the pilot responded to the transmission with another.

TABLE 3-6. CALL SIGN DISCREPANCIES (N = 81)

	Position and Hold	Cleared for Takeoff	Cleared to Land	Hold Short	Other Maneuver	Taxi Instructions: With Frequency Change	Taxi Instructions: Without Frequency Change	Frequency Change	Other
Corrected (47%)	6%	6%	2.5%	1%	5%	2.5%	6%	9%	9%
Uncorrected (53%)	6%	10%	10%	1%	5%	2.5%	5%	6%	7%

In most cases, such call sign discrepancies do not result in any ill effects, or even ambiguity, since there are other cues that controllers can use to identify aircraft. In addition to the visual information that the controllers have in front of them on the flight (e.g., as to the location of the aircraft), they also have the pilot's voice. Without a call sign, the pilot's voice and the content and context of the message are the only cues that the controller has that he/she is still talking to the same aircraft. While this obviously presents an opportunity for error, it should be noted that none of these instances resulted in a problem. It should also be noted that transmissions of some clearances via datalink would eliminate many of these call sign confusions, but would not eliminate accidentally transmitting an instruction intended for another aircraft.

3.3.6 Coincident Factors

Pilots and controllers often informally discuss factors that they believe contribute to communication errors. In addition to message length, pilots often cite high pilot workload, fast controller speech rate and similar sounding aircraft call signs as contributing factors to communications problems. Controllers often cite controller workload, foreign pilots, similar call signs, and blocked transmissions as contributing factors. Voice tape analysis is not an appropriate method of examining pilot and controller workload or cockpit and controller distractions. However, it can offer a glimpse into the other factors. The following factors were examined as possible coincident events:

- similar sounding call signs on the same frequency;
- significant weather conditions;
- communications equipment malfunction;
- blocked transmissions;
- pilot's or controller's use of nonstandard phraseology;
- pilot's or controller's fast rate of speech; and
- pilot's or controller's accent.

Each of the 97 miscommunications (19 readback errors and 78 pilot requests for repeats) was examined for the coincidence of these factors. That is, if any one of these factors was present in an error, it was noted. This was not meant to imply that this factor caused the miscommunication, or even contributed to it. Furthermore, each occurrence of these factors was not counted, only the ones that occurred in conjunction with a miscommunication. Similar call signs on the same frequency was, by far, the most common coincident factor seen. Similar call signs were coincident with 12% of the miscommunications (but contributed significantly to only one communications error). Bad weather was coincident with 5% of the miscommunications and equipment malfunctions were coincident with 2%. Blocked transmissions, pilot's or controller's use of nonstandard phraseology, rate of speech, and accent, were not noted as coincident with any of the miscommunications.

It should be noted that the lack of significant results found in this portion of the analysis should not be interpreted as proof that none of the factors examined constitutes an ATC communications problem. First, the small sample of errors that was found in this study does not allow for an adequate examination of any single one of these factors. In order to examine the impact of any one of these factors on communications, the number of total incidence would need to be compared to the number of occasions in which it was found to contribute to a communications problem. For example, in order to study the similar call sign problem, the number of instances in which similar sounding call signs were on the same frequency would be compared to the number of instances in which this resulted in a communications problem. Such a series of studies was beyond the scope of this analysis. Also, the fact that a specific problem was not observed during the course of this study or the fact that a specific problem is not a common occurrence, does not lessen the severity of the consequences when it does occur. For example, there were no incidents of blocked transmissions that resulted in a communication error in the 48 hours of tape examined. Still, the consequences of a stuck microphone in busy airspace can be very serious. The fact that none of the factors examined were found to have significant effects is not meant to suggest that problems do not exist, nor should it preclude further study.

4. CONCLUSIONS

One of the most striking findings of this analysis was how few errors were found. A readback error rate of less than one percent is a tribute to the pilots and controllers operating in the National Airspace System. Even the most diligent and conscientious pilots and controllers can be involved in a communication error. Complacency and poor radio discipline only compound the problem of the inevitability of human error. It is not possible to reduce the number of communication errors by telling pilots and controllers to "pay attention". However, this analysis suggests that simple changes in current practices could reduce the risk of communication errors. Controllers should be encouraged to keep their transmissions brief and to look for readback errors. Perhaps, erroneous readbacks should be included in the traffic scenarios used in controller training, as a recent ASRS reporter suggests (ASRS Callback, 1992).

It is not realistic to expect air traffic controllers to catch all readback errors while performing their other duties. We are all set up to hear what we expect to hear. While controllers are not exempt from this law of human nature, we require a higher standard of information processing from them. Pilots and controllers need to be aware that catching readback errors is a difficult task, particularly when combined with other duties that need to be performed simultaneously. Often, during a pilot's readback, the controller's attention may already be on the next message that must be issued. This is particularly likely during high workload periods. Pilots need to be encouraged to ask for clarification, rather than expect the controller to catch readback errors. Pilots should also be diligent about using full call signs to acknowledge controller transmissions and to question call sign discrepancies (as in "... Was that for Air Carrier 123?"). Controllers should listen for the call sign, as well as the content, of the pilot's readback. Controllers should also continue to warn pilots when there are similar call signs on the same frequency, whenever possible. Unfortunately, it is not easy to define what constitutes "similar call signs". A list of potentially confusable call signs would be too lengthy to be useful. Clearly, call signs with different airline names, but the same flight numbers are similar, as are same airline flight numbers that differ only by one digit, or one syllable, as in the case of "two" and "ten". Such practices and increased awareness can further reduce the probability of communication problems and further increase the margin of safety.

LIST OF ACRONYMS

ARTCC - Air Route Traffic Control Center

ASRS - Aviation Safety Reporting System

ATC - Air Traffic Control

ATCT - Air Traffic Control Tower

ATIS - Automated Terminal Information Service

SID - Standard Instrument Departure

STAR - Standard Terminal Arrival Route

TRACON - Terminal Radar Approach Control

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