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An Analysis of En Route Controller-Pilot Voice Communications

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The purposes of this analysis were to examine current pilot-controller communication practices in the en route environment. Forty-eight hours of voice tapes from eight different Air Route Traffic Control Centers (ARTCCs) were examined. There were 5,032 controller-to-pilot transmissions and 3,576 clearances (e.g., instructions to maneuver or change radio frequencies, routing changes, etc.) in this sample.

The complexity of the clearances (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 clearance 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 clearances resulted in communications errors. Among the error factors examined were: complexity of the clearance, 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 problems.

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PREFACE

This research was sponsored by the Federal Aviation Administration's Research and Development Service, Human Performance Program (ARD-210). We thank Bill White and John Zalenchak of that office for their support and helpful suggestions. The voice tapes were analyzed, and raw data gathered, by John Chevalier, Nicholas Craddock, Joseph Jarboe and Joseph Moyer of Science Applications International Corporation (SAIC). We thank them and their supervisor, Bryan Brett, for their many hours of tedious analysis. Dr. Jordan Multer assisted in designing the test plan, provided critical comments in the initial stages of this work, and provided a great deal of administrative support to the project. Judith Burki-Cohen reviewed a previous draft of this manuscript and provided many helpful comments.

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 yards (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 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

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 10 286.

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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 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 systems and procedures.

The purposes of this tape analysis were to examine current pilot-controller communication practices in the en route environment and to analyze the communication errors in detail. Forty-seven hours of voice tapes from eight different Air Route Traffic Control Centers (ARTCCs) were examined. There were 5,032 controller to pilot transmissions in this sample. This included 3,576 clearances (e.g., instructions to maneuver or change radio frequencies, routing changes, etc.) and 1,456 requests for information, salutations, controller acknowledgements, etc.

The great majority of clearances contained only one or two pieces of information and were acknowledged with a full or partial readback. Less than one percent of the full readbacks contained an error while two percent of the partial readbacks contained an error. The readback error rate doubled (from .7% to 1.4%) as clearances increased in complexity from three elements to four. The number of miscommunications was significantly higher for clearances containing five or more pieces of information than for simpler clearances. Still, the overall error rate was quite low, except for clearances containing five or more elements. While this category constituted only 4% of the clearances, it contained 26% of the errors found. The most common type of readback error involved frequency changes. Such errors accounted for 37% of the 27 readback errors found in the analysis. The second most common type of error involved crossing restrictions; this accounted for 18% of the readback errors.

Pilots gave their complete call sign (i.e., airline name and flight number or last three alphanumerics for a general aviation aircraft) in only 58% of the erroneous readbacks. No call sign was given in 27% of these readbacks.

There were also 29 instances (.8% of the clearances) in which the pilots responded to transmissions with different call signs than the controllers used. What was surprising about these incidents was that only 39% percent of these call sign discrepancies were corrected.

There were 51 instances (1.4% of the clearances) of pilots requesting that a controller repeat all or part of the transmission. The rate of pilot requests for repeats for clearances containing one to four elements ranges from 1% to 2.5%. The rate for clearances containing five or more elements is almost four percent. There was a 1-3% miscommunication rate (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. Clearly, the more information contained in a transmission, the higher the probability that a controller will need to repeat all or part of that message.

There were only three instances in which a controller did not notice an error in the pilot's readback. This represents 11% of the readback errors and less than one-tenth of one percent of the total number of clearances.

Several factors of interest were examined as coincident to the communication errors. However, no relation was found between any of these factors and communication errors, nor was there any evidence that these factors caused the error. This lack of results was probably due, at least in part, to the small number of errors examined.

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. 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. Controllers also need to be aware that two shorter transmissions may be more effectively transmitted than one longer one to a pilot who would be caught off-guard by a longer message. (Different results would be expected when pilots are prepared for a longer transmission, as in clearance delivery.) Such 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 pilot readbacks of key information (e.g., altitude) are encouraged 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 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 has not yet been documented, nor is it known how often these practices contribute to communication errors. Similarly, a pilot request for the controller to repeat a message ("*say again*") is common occurrence. However, the percentage of all transmissions that need to be repeated has never been determined. This additional transaction adds to a controller's workload and to frequency congestion. Information obtained by sampling pilot-controller voice communications will be 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 a sample (42 hours) of TRACON communications (Morrow, Lee, and Rodvold, in press). They 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 only 3-13% of acknowledgements (depending on the individual TRACON sampled) with partial readbacks being more common for longer ATC messages.

The purpose of this tape analysis is to examine current pilot-controller communication practices and to analyze the communication errors in detail. The current analysis

examines en route communications by sampling ARTCCs. Future analyses will examine pilot-controller communications in ground control, local control (tower), and TRACON. These analyses will document the incidence 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 transmission;
- controllers failing to detect pilot readback errors; and
- controllers relaying multiple instructions in a single transmission.

This analysis is designed to answer two questions:

- How often do these practices occur? (i.e., on what percentage of the communications is this noted?)

- How often do these practices result in a communication error or a pilot's request for a repeat?

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-seven hours of voice tapes from eight different ARTCCs were analyzed. Six hours[1] from each of the following facilities were included in the analysis: Atlanta, Chicago, Kansas City, Los Angeles, New York, Oakland, Seattle, and Salt Lake.[2] These ARTCCs were selected to sample different geographical locations (e.g., east coast, west coast, central), different workload levels, and different traffic mixes (e.g., inclusion of centers with a relatively high proportion of foreign carriers). Twenty-four of the hours of tape analyzed were from periods of high workload (as defined by the facility) and 23 hours were from periods of moderate workload. Twenty-three of the tapes were from high altitude sectors and 24 were from low altitude sectors. The purpose of these selections was to achieve a representative sample of different facility operations (excluding the very low workload periods, e.g., middle of the night, which would yield little interesting data).

Part of the analysis examined miscommunications. This includes communication errors and pilot's requests for repeat of part or all of the clearance. 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, "United 123, fly heading 090" was considered one element. However, "United 123 turn **left** heading 090" was counted as two elements, since there is an opportunity to mistakenly turn right. Usually, the counting is straightforward. Changes in altitude, heading, speed, and altimeter settings are each considered to be one element. Crossing restrictions and routing changes can contain many elements. For example, "Northwest 123, cross **ten** miles **west** of **Pullman** at and maintain flight level **200**" was considered to contain four elements. For the purposes of quantifying the complexity of all transmissions issued, changes in radio frequencies were considered to contain one piece of information. For the error analysis, however, this was true only when the change did not involve contacting a new facility. For example, "US Air 123 contact Minneapolis Center 118.82" was considered one piece of information if the pilot was already on a Minneapolis Center frequency. For the purposes of error analysis only, that same message was considered as two pieces of information, if the pilot received it while on a Chicago Center frequency.

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

[2] Due to a faulty tape, only five hours of tape were analyzed from Seattle ARTCC. Three hours were from high workload periods and two were from moderate workload periods. Three hours were from low altitude sectors and two were from high altitude sectors.

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 clearance. The direction of the maneuver was only considered a separate element when it presented a separate opportunity for error. If an aircraft is at 10,000 feet and is instructed to climb and maintain 12,000, the pilot knows he cannot descend; having processed the 12,000 correctly, the climb is understood. However, if a pilot is instructed to turn left heading 120, then both the direction of the turn and the heading was counted as separate elements, because each present an opportunity for error. 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. All elements are not assumed to impose the same memory load. It is probably easier to remember to turn **left** to a specific heading than to remember an unfamiliar radio frequency. Yet, for counting purposes, each would be considered an element. The error analysis does, however, examine errors with respect to the type of information transmitted.

The tape analysis was conducted by four analysts (one former controller and three pilots). All communication errors were transcribed and set aside for separate analysis.

3. ROUTINE COMMUNICATIONS PRACTICES

There were 5,032 controller to pilot transmissions on the 47 hours of voice tapes analyzed. This included 3,576 clearances (e.g., instructions to maneuver or change radio frequencies, routing changes, etc.) and 1,456 requests for information, salutations, controller acknowledgements, etc.

3.1 CLEARANCE 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, Morrow, Lee, and Rodvold (in press) 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 1 shows the distribution of clearances by complexity level. The great majority of clearances contained only one or two pieces of information. Forty-eight percent of the clearances contained one element (e.g., a frequency change) and 30% contained two elements. Eleven percent of the clearances contained three elements, and 6% contained four elements. The remaining five percent of the clearances examined contained five or more elements.

Table 1. Percentage of Clearances as a Function of Message Complexity

Complexity Level	Percentage of all Clearances
1	48%
2	30%
3	11%
4	6%
4	3%
6	1%
7	0.3%
8	0.3%
9 or more	0.2%

3.2 CLEARANCE ACKNOWLEDGEMENT

As Table 2 shows, the vast majority of the 3,576 clearances were acknowledged with a full or partial readback. Seventy-one percent of the clearances were acknowledged with a full readback and 12% were acknowledged with a partial readback. Six percent of the clearances were directly acknowledged without a readback (e.g., with a "roger"), while eight percent were indirectly acknowledged (e.g., with a question, or a request for a different clearance or additional information). This included two percent of the clearances being followed by a pilot request for a full or partial repeat (one percent request for full repeat and one percent request for partial repeat). An additional .7% of the clearances resulted in a full or partial repeat due to readback errors. Three percent of the clearances were not acknowledged and had to be repeated by the controller.

Table 2. Pilot Responses to ATC Clearances

Full Readbacks	71%
Partial Readbacks	12%
Acknowledgement Only	6%
Other Replies	8%
No Acknowledgement	3%
Total	100%

Less than one percent of the full readbacks contained an error while two percent of the partial readbacks contained an error. This error rate refers only to instances in which the pilot read back something different (e.g., a number, direction or location) than what the controller originally said. There was also one error in the "acknowledgement only" category where the pilot acknowledged a frequency change with only a "roger" and then had to call back to get the correct frequency. These readback errors will be examined in detail in the section on miscommunications.

3.3 MISCOMMUNICATIONS

3.3.1 Clearance 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 clearance, the higher the memory load imposed upon the pilot. There were 27 communication errors found in the 47 hours of tape analyzed. This represents less than one percent of the 3,576 clearances issued. Figure 1 shows the percent of pilot readback errors as a function of the complexity of the controller's original clearance. These percentages were obtained by dividing the number of errors made with clearances at that complexity level by the total number of clearances

at that level. For example, there were seven errors at complexity level one and 1,733 clearances that contained only one element. This yields a readback error rate of .004 or .4%. As Figure 1 shows, the readback error rate doubles (from .7% to 1.4%) as clearances increase in complexity from three elements to four. Still, the overall error rate is quite low, until clearances containing five or more elements are examined. While this category constitutes only 4% of the clearances examined, it constitutes 26% of the errors found. This very small percentage of longer clearances accounts for a disproportionate number of the readback errors found in this environment.

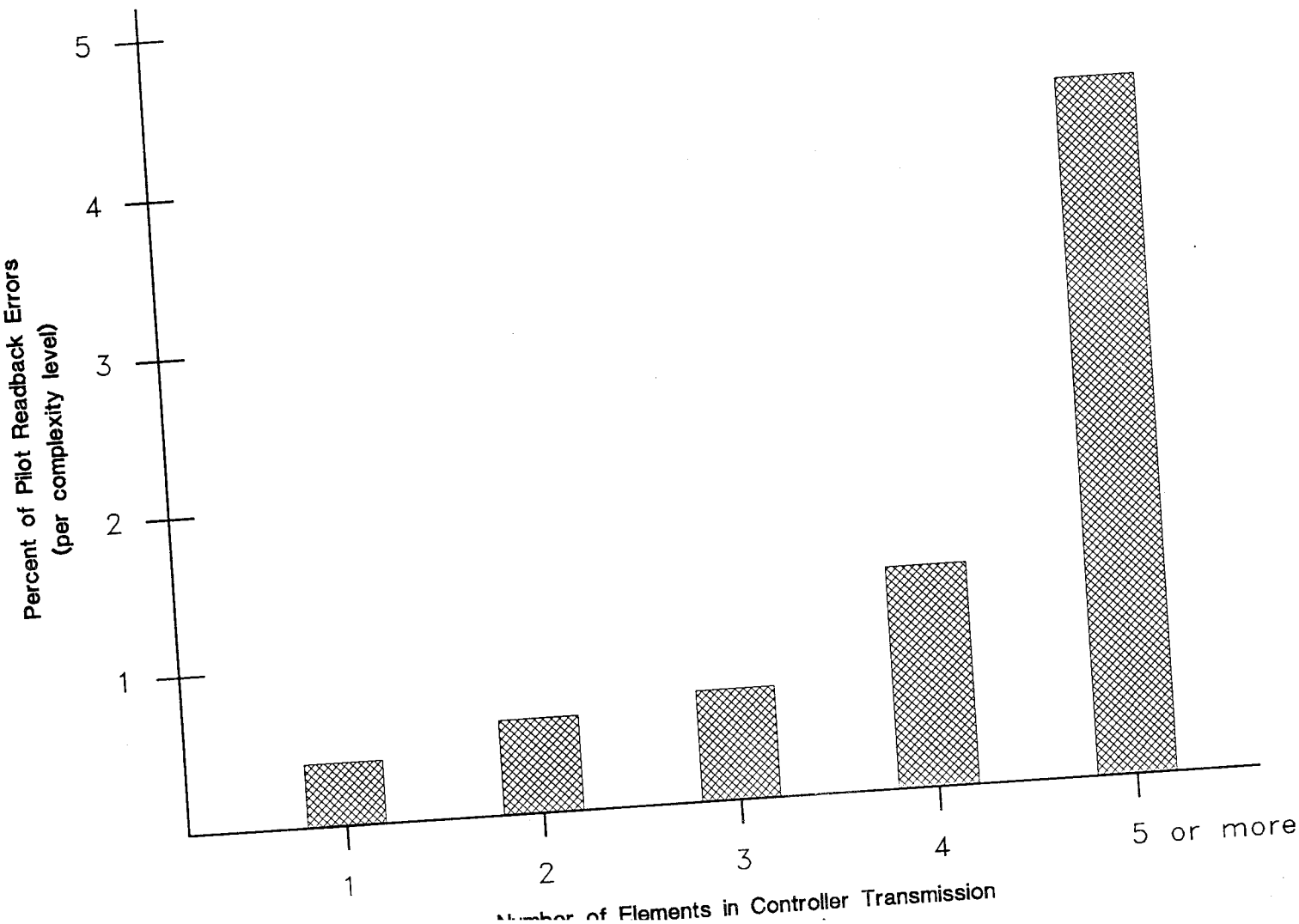
3.3.2 Clearance Complexity and Incidence of Full Readbacks in Communication Errors

The shorter the controller's transmission, the more likely the pilots were to respond with a full readback. Table 3 shows the incidence of full readbacks that contained errors as a function of message complexity. Even with clearances containing four pieces of information, two-thirds of the pilots read back the entire clearance. With five or more pieces of information, the number of full readbacks dropped to one in five.

Table 3. Percentage of Full Readbacks in Communication Errors as a Function of Message Complexity

Complexity Level	Number of Readback Errors	Number of Full Readbacks	Percentage of Full Readbacks
1	7	5	71%
2	7	6	86%
3	3	2	66%
4	3	2	66%
5	5	1	20%
6	1	0	0%

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


Percent of Pilot Readback Errors
(per complexity level)
5
4
3
2
1
1
2
3
4
5 or more
Number of Elements in Controller Transmission

3.3.3 Use of Call Signs in Readback Errors

Pilots gave their complete call sign (i.e., airline name and flight number or last three alphanumerics for a general aviation aircraft) in only 58% of the readbacks containing an error. A partial call sign (e.g., airline name alone or flight number alone) was given in an additional 15% of the readbacks. No call sign was given in 27% of these readbacks. Of the erroneous readbacks given without call signs or with only a partial call sign, 73% were from Part 121 or Part 135 air carriers.

3.3.4 Clearance 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 51 instances (1.4% of the clearances) of pilots requesting that a controller repeat all or part of the transmission. Figure 2 shows the percentage of clearances followed by a pilot's request to repeat all or part of the transmission. The results are similar to those for pilot readback errors. The rate of pilot requests for repeats increases as clearance complexity increases. The percentage of clearances that are followed by a pilot's request for a repeat ranges from 1% to 2.5% for transmissions containing one to four elements. The rate for clearances containing five or more elements is almost four percent.

3.3.5 Clearance Complexity and Miscommunications

The clearances issued by controllers that are followed by a pilot's request for a repeat of some or all of the transmission combined with the clearances that are followed by a readback error represent the number of miscommunications. (This does not equal all of the clearances that need to be repeated by controllers, since an additional three percent of all clearances needed to be repeated due to a lack of pilot response). Figure 3 shows the proportion of miscommunications requiring a full or partial repeat as a function of the complexity of the controller's transmission. As can be seen in Figure 3, there is a 1-3% miscommunication rate for clearances containing one to four pieces of information and a 8% miscommunication rate for transmissions containing five or more elements. The number of controller transmissions that needed to be replaced due to readback errors and pilots' requests for repeats is significantly higher for clearances containing five or more pieces of information than for clearances containing one to four pieces of information (χ^2 (1 df α = .005) = 7.88). Clearly, the more information contained in a transmission, the higher the probability that a controller will need to repeat all or part of that message.

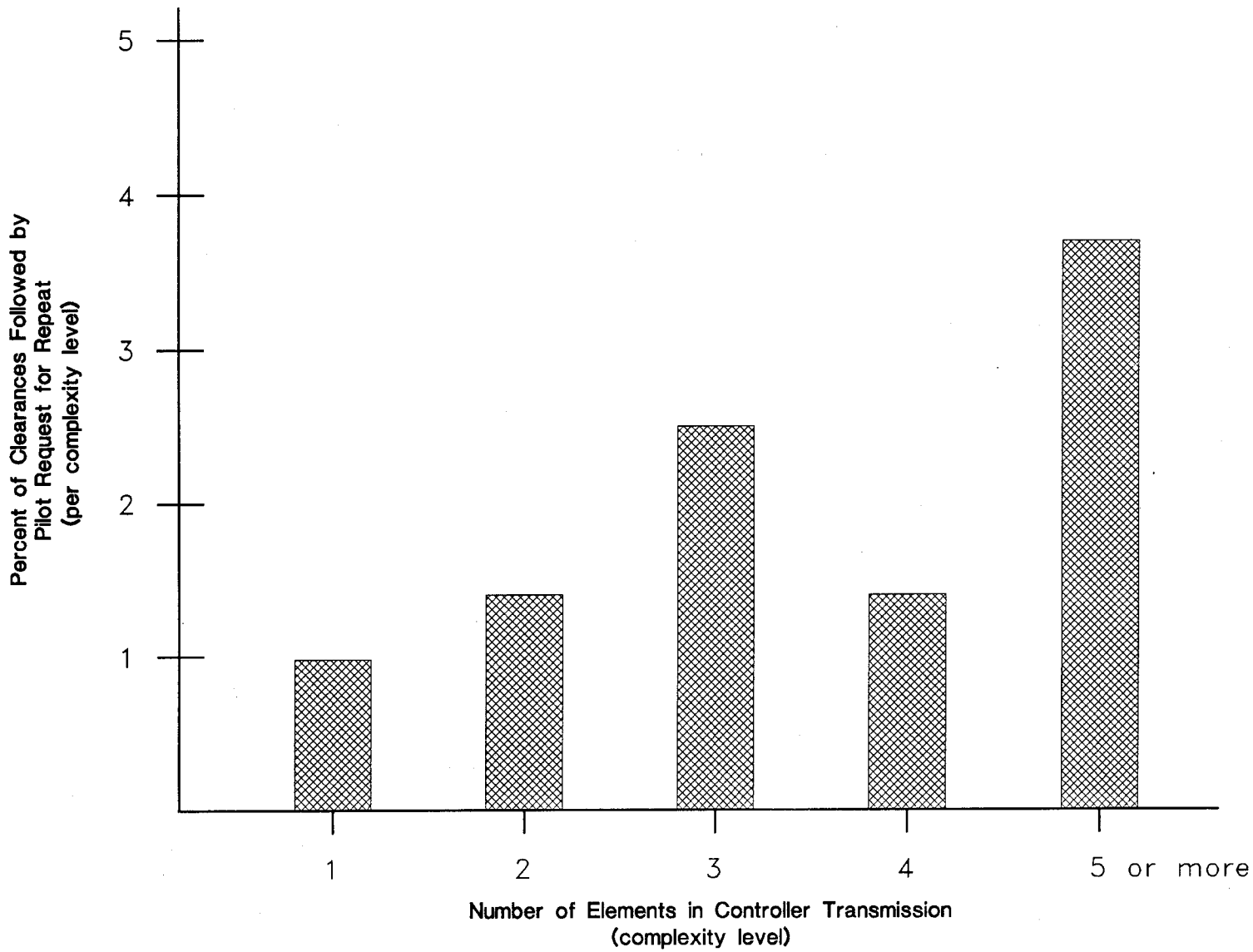


Figure 2. Percent of Clearances Followed by Pilot Request for Repeat as a Function of Clearance Complexity

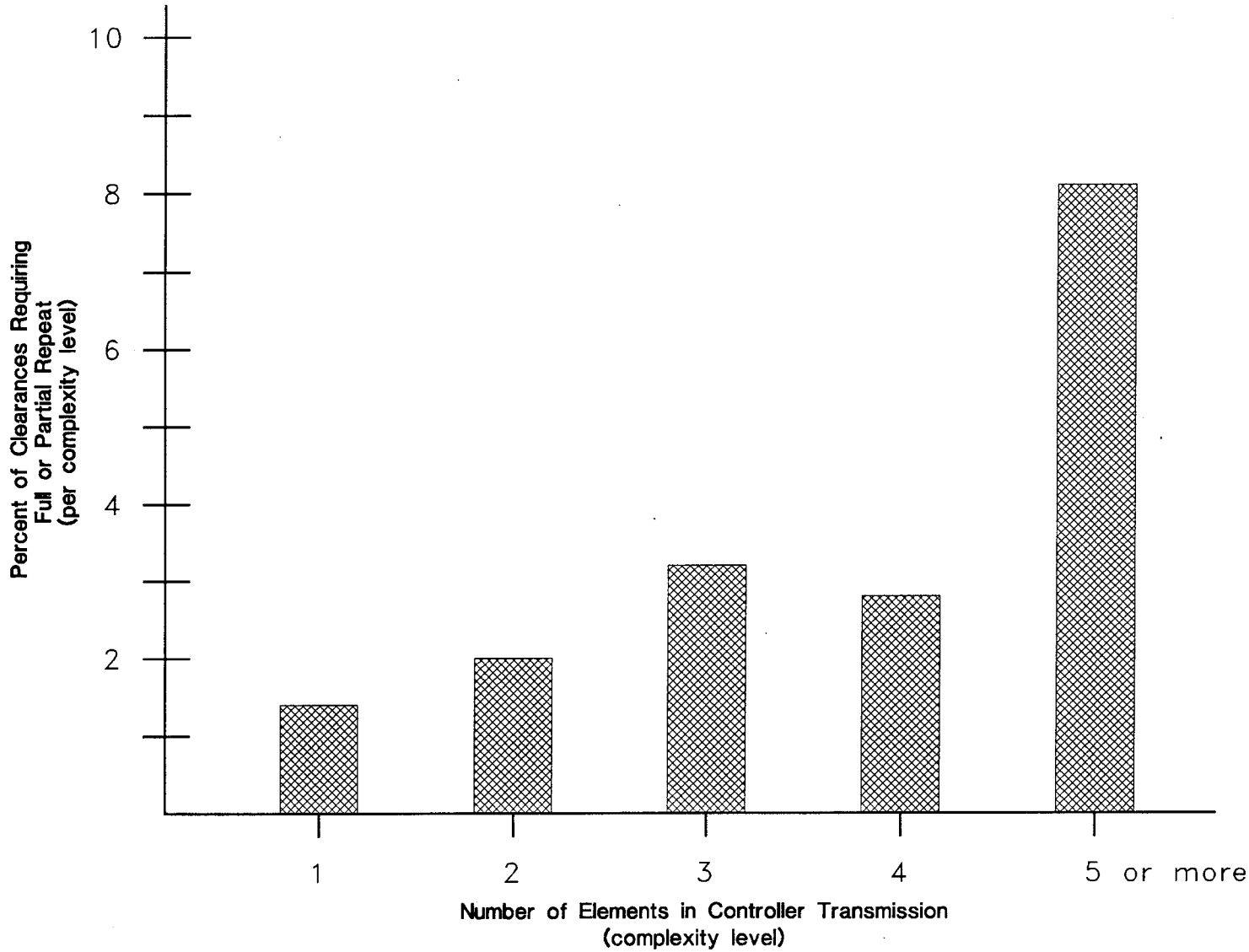


Figure 3. Percent of Clearances Requiring Full or Partial Repeat as a Function of Clearance Complexity

3.3.6 Hearback Errors

There were only three instances in which the controllers did not notice an error in the pilot's readback. This represented 11% of the readback errors and less than one-tenth of one percent of the total number of clearances. In one instance, a pilot was told to "descend and maintain one two thousand". The pilot read back "out of two zero zero for **two** thousand". The controller's following transmission gave the pilot the local altimeter setting. The other two readback errors involved a frequency change and a speed restriction. In the latter case, the controller said, " Air Carrier 1-92, descend and maintain one seven thousand, City X altimeter two niner niner seven, maintain 200 knots for spacing." The pilot's response was "Air Carrier 1-92, down one seven thousand, 300 knots for spacing at City X two nine seven seven." The controller caught the error in the readback of the altimeter (the last thing he heard), but missed the error in the readback of the speed. There were too few readback and hearback errors found in this study to contribute to our understanding of hearback errors.

3.3. 7 Communication Errors and Type of Information

Table 4 shows the distribution of readback errors as a function of the type of information in error. The most common type of readback error involved frequency changes. Such errors accounted for 41% of the 27 readback errors found in the analysis. Sixty-four percent of these errors involved frequency changes that required contacting a new facility. That is, seven out of the eleven radio frequency readback errors found involved a clearance to contact a new facility (e.g., to contact Minneapolis Center while on a Chicago Center frequency). Only four of the ten involved changing frequencies within the same facility. Eighteen percent of the readback errors involved crossing restrictions. These crossing restrictions contained an average of 5 elements per transmission. Eleven percent of the readback errors contained inaccurate altitudes and 7% contained inaccurate altimeter settings.

In addition to these readback errors, there was one instance of the wrong aircraft accepting a transmission intended for another aircraft. This required two additional controller transmissions - one to tell the first aircraft to stay on the frequency and another to contact the intended aircraft. There were also eight instances of pilots transmitting on the wrong frequency. In most of these cases, only one additional controller transmission was required to rectify the situation. That is, the controller informed the pilot that he/she was on the wrong frequency and reissued the correct frequency. In one instance, however, the pilot erroneously called the controller (who had just instructed him to change frequencies), but then the pilot changed frequencies without waiting for the controller's response. The controller made two futile attempts to identify the caller (e.g., "aircraft calling center, say again").

Table 4. Distribution of Readback Errors by Type of Information

Type of Information in Readback Error	Number of Readback Errors	Proportion of Readback Errors
Radio frequency	11	41%
Crossing restrictions	5	18%
Altitude	3	11%
Altimeter setting	2	7%
Routing changes	2	7%
Heading	1	4%
Speed	1	4%

3.3.8 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, non-native speaking 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 non-standard phraseology;
- pilot's or controller's fast rate of speech; and
- pilot's or controller's accent.

Each of the 27 communication errors 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 error, or even contributed to it. Furthermore, each occurrence of these factors was not counted, only the ones that occurred in conjunction with a communications error. Each of the following were noted in one communication error: similar sounding call signs, significant weather, blocked transmission, controller's fast speech rate, and pilot's foreign accent. Pilot use of non-standard phraseology was found in three of the communications errors. There was no relation found between any of these factors and communication errors, nor was there any evidence that these factors caused the error.

For example, "Hey, understand" is not a standard part of an acknowledgement, but it did not contribute to this readback error of the proper heading in the following example:[3]

> CONTROLLER: "Air Carrier 15-65, fly heading 1, correction fly heading 1-8-0. Intercept Victor 1-4-3. Resume own navigation. Descend and maintain 1-2 thousand."
>
> PILOT: "Hey, understand 1-2-0 on the heading and, uh, come out at 1-6 thousand or 1-2 thousand?"
>
> CONTROLLER: "Air Carrier 15-65, the heading 1-8-0 to intercept Victor 1-43, maintain 1-2 thousand."
>
> PILOT: "OK, 1-8-0 to intercept Victor 1-43, and we're out of 16 for 12."

This example also illustrates the problem with multiple messages communicated in a single transmission. Even the simple "correction" may add to the mental processing load of the pilot by lengthening the entire message, even though the word "correction" itself does not need to be remembered. A controller's self-correction does add to the processing load when it replaces information. The following example illustrates this point. It also illustrates pilot tendencies to provide only a partial readback with lengthy clearances.

> CONTROLLER: "Air Carrier 16-83, cross XXX intersection at or below 1-6 thousand, descend and maintain 1-2 thousand, (local) altimeter 2-9er-9er-2, leaving 1-6 thousand reduce speed to 2-5-0, (pause) correction 2-8-0 knots."
>
> PILOT: "OK, we're going down to 12, and you want us to cross what?
>
> CONTROLLER: "XXX intersection at or below 1-6 thousand, descend and maintain 1-2 thousand, Air Carrier 16-83."
>
> PILOT: "OK, we can do that, 16-83."

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

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[3] Note: All of the actual examples used in this report have been de-identified with respect to names of air carriers, locations, and ARTCCs.

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 47 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.

3.3.9 Call Sign Discrepancies

There were 29 instances in which a pilot responded to a transmission with a call sign that was different than the one used by the controller.[4] In none of these instances was there evidence that the other call sign was actually another aircraft on the same frequency. Table 5 shows the distribution of these call sign discrepancies. Fifty-one percent of these transmissions contained maneuvers or other important clearances, 11% contained instructions to change frequencies, and 38% were less critical calls (such as initial check-ins). What was most surprising about these incidents was that only 39% percent of these call sign discrepancies were corrected. Only three (11% of the call sign discrepancies) were corrected with direct pilot questions or statements (e.g., "Was that for Airline 123?"), and another three were corrected by direct controller questions or statements. Five of the discrepancies (17%) were indirectly corrected by either the pilot or controller changing the call sign on the next transmission to conform to what the other party used. The majority (62%) of the call sign discrepancies went uncorrected as the controller called the aircraft with one call sign and the pilot responded to the clearance with another.

Table 5. Call Sign Discrepancies

	Maneuvers and Frequency Changes	Other
Corrected	8 (28%)	3 (11%)
Uncorrected	10 (34%)	8 (27%)

[4] In addition to these call sign confusions, there were two other instances in which the controller and pilot used different call signs. These cases were not included in the figures given above, since the discrepancy was in the first or second digit of a general aviation call sign (e.g., "Cessna 1234A" vs. "Cessna 1334A") and both parties later used the last three alphanumerics.

In one interesting case, the pilot attempted to correct the controller's use of the wrong call sign, but the controller missed the correction and the pilot did not pursue the issue.

PILOT: "Center XXX, Air Carrier 3-60 with you level one five thousand"

CONTROLLER: "Air Carrier 3-62, Center XXX roger"

PILOT: "That was 3-62 sir, we're at one five thousand."

CONTROLLER: "Air Carrier 3-60, roger, the (local) altimeter is three zero two six."

Later, the same aircraft was cleared for a visual approach. Eventually, the aircraft was instructed to change frequencies. Throughout these two controller transmissions and two pilot acknowledgements, the controller called the aircraft using 3-60 and the pilot responded with 3-62.

Clearly, there are other cues that controllers 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 altitude and 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 errors, it should also be noted that none of these instances resulted in a serious problem.

4. SUMMARY AND CONCLUSIONS

Even the most diligent and conscientious pilots and controllers can be involved in a miscommunication. 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). Pilots should be encouraged to use their call signs when acknowledging clearances, ask for a repeat of any portion of the clearance on which they have a doubt, and to question call sign discrepancies (as in "... Was that for Air Carrier 123?"). Pilots should not accept and readback a clearance on which they have a question with the expectation that the controller will pick up any errors in the readback or automatically correct the call sign discrepancy. Clearly, it is safer to directly ask for a clarification than to "play the odds" on a clearance. Often, during a pilot's readback, the controller's attention may already be on the next clearance that must be issued. This is particularly likely during high workload periods.

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. From a human factors standpoint, 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. Pilots need to be encouraged to ask for clarification, rather than expect the controller to catch readback errors. Controllers also need to be aware that two shorter transmissions may be more effectively transmitted than one longer one to a pilot who would be caught off-guard by a longer message. Specifically, the data suggest that unexpected en route transmissions contain no more than four pieces of information. (Different results would be expected when pilots are prepared for a longer transmission, as in clearance delivery.) Such increased awareness can further reduce the probability of communication problems and further increase the margin of safety.

REFERENCES

ASRS Callback Number 163, Readback/hearback - Some fresh ideas, December 1992.

Morrow, D., Lee, A., & Rodvold, M. (in press). Analysis of problems in routine controller-pilot communication. *International Journal of Aviation Psychology*.