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An Analysis of TRACON (Terminal Radar Approach Control) Controller - Pilot Voice Communications

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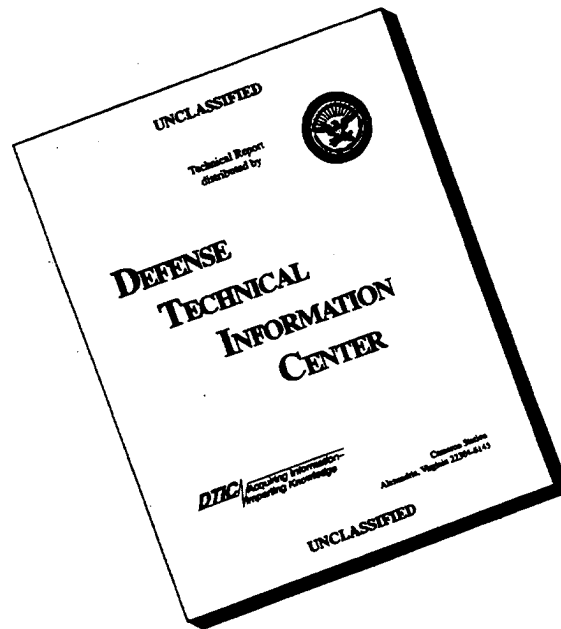
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13. ABSTRACT (Maximum 200 words)

The purpose of this analysis was to examine pilot-controller communication practices in the TRACON (Terminal Radar Approach Control) environment. Forty-eight hours of communications recorded on the voice tapes from eight TRACONS were analyzed. There were 13,089 controller-to-pilot transmissions examined in this study. This included 9,409 clearances (e.g., assignment of altitude; instructions to change heading, speed, or radio frequencies; instructions for arrival, etc.) and 3,680 requests for information, salutations, etc.

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

Fewer than one percent of the messages resulted in communications errors. Among the error factors examined were: complexity of the message, type of acknowledgment, use of call sign in the acknowledgment, 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

This research was sponsored by the Federal Aviation Administration's Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100). We thank Lawrence Cole of that office, and John Zalenchak for their support and helpful suggestions. The voice tapes were analyzed, and raw data gathered, by Ben Cameron and John Chevalier of Science Applications International Corporation (SAIC). David Malek of SAIC performed much of the data analysis and provided other valuable technical support. We thank them 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. 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	

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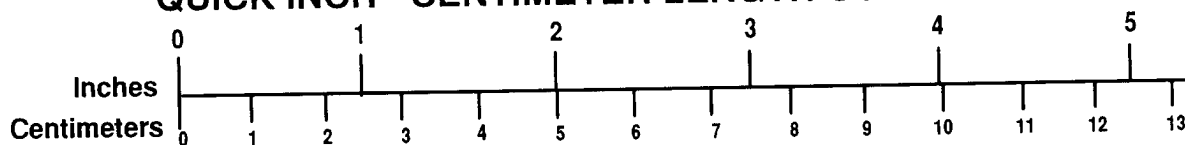
AREA (APPROXIMATE)	
1 square centimeter (cm ²)	= 0.16 square inch (sq in, in ²)
1 square meter (m ²)	= 1.2 square yards (sq yd, yd ²)
1 square kilometer (km ²)	= 0.4 square mile (sq mi, mi ²)
10,000 square meters (m ²)	= 1 hectare (ha) = 2.5 acres

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

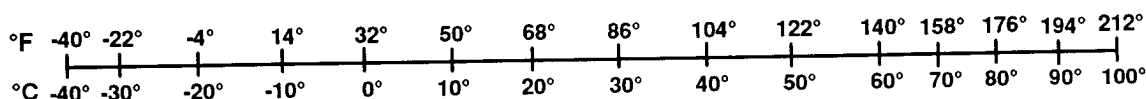
VOLUME (APPROXIMATE)	
1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m ³)	= 36 cubic feet (cu ft, ft ³)
1 cubic meter (m ³)	= 1.3 cubic yards (cu yd, yd ³)

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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 misunderstanding. Depending on the nature of the error and surrounding circumstances, 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 terminal radar approach control (TRACON) environment and to analyze the communication errors in detail. Forty-eight hours of voice tapes from eight TRACONs were examined. There were 13,089 controller-to-pilot transmissions in this sample. This included 9,409 clearances (e.g., assignment of altitude; instructions to change heading, speed, or radio frequencies; instructions for arrival, etc.) and 3,680 requests for information, salutations, etc.

The majority of these controller messages (59%) contained only one or two pieces of information. Approximately 1% of the readbacks contained an error. Forty percent of these errors were not noticed by the controller or not corrected through further communication. Another 1% of the messages (127 instances) resulted in a pilot's request for a repeat of all or part of the transmission.

The rate of readback errors increased slightly, but steadily, with the number of pieces of information in the controller's transmission. That is, the more complex the transmission, the more likely that the pilot's readback would contain an error.

The three most common types of readback error in the transmissions in this environment involved aircraft headings, radio frequency changes, and instructions regarding altitude. Thirty-six percent of the readback errors found in this sample were associated with instructions for changing heading. Twenty-six percent of the readback errors were associated with frequency changes. Another 17% of the readback errors related to altitude clearances. This distribution of errors is not representative of the probability of an error, given a type of clearance. Given the total number of pilot readbacks of headings, altitudes, and radio frequencies, readback errors were most likely with radio frequencies and least likely with altitudes.

Pilots gave their complete call sign (i.e., airline name and flight number or last three alphanumerics for a general aviation aircraft) in 56% of the readbacks. A partial call sign (e.g., airline name alone or flight number alone) was given in an additional 31% of the readbacks, and no call sign was given in 13% of the readbacks. A full readback was given in response to 60% of the controller messages, however, a full readback with a complete call sign was only given in 37% of the pilot responses. Interestingly, pilots are slightly more diligent about responding with a full readback than they are with their complete call sign.

There were also 79 instances (.8% of the messages) in which the pilots responded to controller transmissions with different call signs than the controllers used. Half (53%) of these call sign discrepancies remained uncorrected as the controller continued to use a different call sign than the pilot who responded to the transmission.

Several factors of interest were examined as coincident to the communication errors. However, the only factor that was found to be associated with several miscommunications 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 misunderstanding. 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, pilots often 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 not uncommon, particularly on congested frequencies during extremely busy traffic periods. Similarly, it is common for a pilot to request the controller to repeat a message ("*say again*"). 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 as a component of an evaluation of the efficiency of sending different types of ATC messages via data-link.

Previous extensive work in ATC voice tape analysis has focused on ground, local control (tower), and on en route communications. These studies examine communication practices in detail, many of which are specific to each environment. One striking similarity in the findings is that all of these studies - of en route (Cardosi, 1993), tower (Cardosi, 1994), and ground control communications (Burki-Cohen, 1995) - found an error rate of less than one percent. Most of these errors involved lengthy controller transmissions that resulted in erroneous pilot readbacks. There were also several instances (an additional 1% of the transmissions) in which pilots responded to controller transmissions with different call signs than the controller had used. Many of these call sign discrepancies went uncorrected as the pilot and controller continued to use different call signs in their transmissions.

In the TRACON (Terminal Radar Approach Control) environment, Morrow, Lee, and Rodvold (1993), examined communications from four different TRACONs and also 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 acknowledgments (depending on the individual TRACON sampled) with partial readbacks being more common for longer ATC messages. The purposes of this tape analysis were to examine current pilot-controller communication practices in the TRACON environment and to analyze the communication errors in detail. These analyses document the incidence (i.e., on what percentage of the communications is this noted?) and, to some extent, the consequences of the following practices:

- pilots acknowledging controller transmissions with complete or partial readbacks;
- pilots acknowledging controller transmissions with full or partial call signs;
- pilots responding to controller transmissions with only an acknowledgment (i.e., "roger" or a mike click);
- requests for repeat of controller transmissions;
- controllers relaying multiple instructions in a single transmission
- pilot readback errors, and
- controllers failing to detect pilot readback errors.

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. Also, the use of tape analysis to study the consequences of these practices is limited, since the consequences may not be apparent in that sector on the (hour-long) tape. Because of these limitations, 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.

2. METHOD

Forty-eight hours of voice tapes from TRACON positions at eight different facilities were analyzed. Depending on the quality of the tapes received, between four and eight hours from each of the following facilities were included in the analysis: Boston, Denver, Dallas-Fort Worth, Los Angeles, Miami, New York, Phoenix, and Seattle. The tapes from each facility were from non-consecutive hours in single hour increments. 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 facilities 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. Within each workload level, one-half of the hours were from arrival sectors and one-half were from departure sectors. The purpose of these selections was to achieve a representative sample of different operations excluding the very low workload periods, (e.g., middle of the night) which would yield few data points and findings that might not apply to busier periods.

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. For the purposes of this report, all errors have been deidentified, that is, the ATC facility name and all airline names and flight numbers have been deleted. Pilot readback errors 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 for 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, "AirCarrier 123, heading two five zero" was considered two elements ("heading" and "250"). This could mistakenly be read back as "speed 250" or "heading 150". Usually, the counting is straightforward. Numbers that constitute headings, speeds, runways, frequencies, etc., are each considered to be one element as are "left", "right", and the terms "heading", "speed", etc. As any pilot knows, departure or approach instructions can contain many elements. Controller transmissions containing clearances to departure or approach can also include traffic advisories, wind advisories, and other information. Even simple departure or approach instructions can contain more than a few pieces of information. Consider the following example, "Aircraft XX, change runway to two-five left, cross Santa Monica VOR at or above seven thousand, descend and maintain three thousand five hundred". This transmission may have been as succinct as practical, but still contained five pieces of critical information.

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 maintain a present altitude than it is to remember an

unfamiliar radio frequency. Yet, for counting purposes, each would be considered as one element. The number of pieces of information is not the only determining factor in readback accuracy. The error analysis also examines errors with respect to the type of information transmitted.

3. ROUTINE COMMUNICATIONS PRACTICES

There were 13,089 controller-to-pilot transmissions on the 48 hours of voice tapes analyzed. This included 9,409 messages of substance (e.g., assignment of altitude, instructions to change heading, speed, or radio frequencies, etc.) that were included in this study. The other 3,680 controller transmissions consisted of requests for information, salutations, controller acknowledgments, etc.; these 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. In the TRACON environment, Morrow, Lee, and Rodvold (1993) found that incorrect readbacks were more frequent for communications containing two or more pieces of information than those containing only one. In a part-task flight simulation study, Morrow and Rodvold (1993) found that incorrect readbacks and pilot requests for clarification were more frequent after a single long message (containing four commands) than after two shorter messages (each containing two commands). A study of en route communications showed that most of the readback errors involved lengthy controller transmissions. In that study, 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. While this relation between message complexity and miscommunications was striking in the en route environment, it was not as strong in the ground control study and weaker still in the study of local tower communications.

The effect of message complexity does not stop with communication errors. In a study of altitude deviations, pilots said that almost half (49%) of their altitude deviations involved multiple instructions being given in the same controller transmission (MiTech, Carlow and FAA, 1992).

Table 3-1 shows the distribution of messages by complexity level. (These percentages do not add up to 100 due to rounding.) The majority (59%) of messages contained one or two pieces of information. Fifteen percent of the messages contained three elements and 25% of the messages contained four or more elements. An example of a lengthy transmission is the following. "AirCarrier XX, five miles from [location X], turn right heading one niner zero, maintain three thousand until established on the localizer, cleared ILS Runway two two **left**¹, approach speed one eight zero until [location X]." It is not too surprising that after this clearance, the pilot erroneously readback (only), "cleared ILS two two **right**".

1. Text emphasis in all readback errors was added by author, i.e., it was not emphasized by the controller.

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

Complexity Level	Percentage of all Messages
1	32%
2	27%
3	15%
4	10%
5	6%
6	4%
7 or more	5%

3.2 CLEARANCE ACKNOWLEDGMENT

As Table 3-2 shows, the vast majority of clearances were acknowledged with a full or partial readback. Sixty percent of the messages were acknowledged with a full readback and an additional 26% were acknowledged with a partial readback. Only five percent of the messages were only acknowledged (e.g., with a “roger”). Seven percent were acknowledged indirectly (e.g., with a question, or a request for a different clearance or additional information). Two percent of the controller messages were not acknowledged at all. Included in the category of “acknowledgment only” were (thankfully only) 15 microphone clicks that were used as a form of acknowledgment. These **mike clicks** were never used to respond to a controller for the first time (on a given frequency). However, six (43%) of these mike clicks were given as a pilot's response to a controller transmission that contained a clearance or control instruction (e.g., a heading, speed, frequency change). The majority of the mike clicks were in response to a controller's repeat of previously given instruction, or transmissions that contained information only, such as “radar contact, expect runway XX”.

TABLE 3-2. PILOT RESPONSES TO ATC MESSAGES

Full Readbacks	60%
Partial Readbacks	26%
Acknowledgment Only	5%
Other Replies	7%
No Acknowledgment	2%
Total	100%

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 the controller to ensure that the pilot has received the message. The consequences of such errors are not likely to appear in this type of tape analysis, since the analysis examined the communications from one TRACON position over the course of an hour and did not follow individual flights from one radio frequency to another (e.g., from one sector to another or from the TRACON to the tower).

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 speed restriction, altitude, or heading) 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 56% of the readbacks. A partial call sign (e.g., airline name alone or flight number alone) was given in an additional 31% of the readbacks, and no call sign was given in 13% of the readbacks. A full readback with a complete call sign was the most common response to a clearance, but accounted for only 37% of the pilot responses. A full readback with a partial call sign was the second most common response, accounting for 24% of the responses. Interestingly, pilots are slightly more diligent about responding with a full readback than they are with their complete call sign.

The potential hazards inherent in responding with an incomplete call sign are apparent in the following example. The controller issues a speed restriction to AirCarrier **XX 51**. In fact, the controller intended to give AirCarrier **XX 1751** the speed restriction. A pilot responded to this instruction with a question “Was that for **XX 51**?”. In this instance, both aircraft with the call sign of AirCarrier **XX 51** and AirCarrier **XX 1751** were on the frequency. The controller then repeated the instruction to **XX 1751**. In another example, a pilot accepted a clearance issued to a different aircraft. The instruction “Turn ten degrees left, descend and maintain one one thousand” was issued to AirCarrier **YY 203**. However, a same company aircraft readback “ten degrees left, 11 thousand, **YY 785**”. In this era of hubs (where many aircraft from the same company are operating simultaneously) and the inevitable 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.

3.3 MISCOMMUNICATIONS

When a pilot responds to a controller's transmission with an incorrect readback of that transmission, this is called a **readback error**. If a controller does not catch or correct the readback error, this is called a **hearback error**. In this study, **miscommunications** consist of readback errors, hearback 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. 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, when what is expected is not what is transmitted. For example, “Good day AirCarrier XX, reduce **speed** to two three zero, contact approach 1-3-3-point-1-5.” was read back as, “two thirty on the **heading** and say speed for AirCarrier XX.”. The controller repeated: “The speed is two-thirty and frequency 1-3-3-point-1-5”. The second pilot readback was: “3-3-1-5, two thirty on the heading”. The pilot was still confusing speed with heading; this readback error was not corrected in the remainder of the tape.

There are many other important factors that 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 factors that can be studied, such as complexity of controller transmission and type of information in error, so that we can identify the patterns of errors and gain insight into how to prevent them.

3.3.1 Message Complexity and Readback Errors

Logically, the more information contained in a single transmission, the greater the opportunity for an error and the higher the probability of an error. The more elements in a message, the higher the memory load imposed upon the pilot. There were 81 readback errors found in the 48 hours of tape analyzed. (Four of the pilot readbacks contained two errors.) This represents less than one percent of the 9,409 clearances issued. Table 3-3 shows the percent of pilot 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 number of readback errors at each complexity level. Column 3 shows the percentage of readback errors at each complexity level. These percentages were obtained by dividing the number of errors by the number of full and partial readbacks given in response to the messages at that complexity level. For example, there were 17 readback errors at complexity level five and 475 pilot readbacks to controller messages that contained five elements. This yields a readback error rate of 3.6%. The readback error rate increases slowly, but steadily, with complexity level. That is, the more information contained in a single transmission, the higher the probability of a readback error.

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

Complexity Level	Number of Readback Errors	Percentage of Readback Errors
1	16	.7%
2	12	.5%
3	13	.9%
4	14	1.5%
5	17	3.6%
6	2	.7%
7 or more	7	1.7%

While the results are not perfectly linear, it is striking that most of the readback errors found in this study were preceded by complex transmissions. **While clearances that contained four or more pieces of information made up only 26% of the readbacks, they accounted for 51% of the readback errors found in this study.** While only 16% of the clearances contained five or more pieces of information, they accounted for 33% of the readback errors. These findings are similar to the results found in the en route environment. An analysis of voice tapes from Air Route Traffic Control Centers (ARTCCs) also showed that the readback error rate increased with the complexity of the controller's transmission (Cardosi, 1993). Furthermore, en route clearances containing five or more pieces of information constituted 4% of the messages examined, and 26% of the readback errors found in that sample.

While message complexity does seem to have a direct effect on the accuracy of the pilot's readback, clearly it is not the only determining factor. Some of the information contained in the very lengthy transmissions in a TRACON environment are predictable, based on the information available on the ATIS and via the partyline (i.e., transmissions between the controller and other aircraft). (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, e.g., hear the call sign, write down the clearance.) 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 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. 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 actually transmitted.

Finally, it should be noted that this analysis, by default, counted each piece of information (e.g., each runway) 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 respond.

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. The most common type of readback error involved heading instructions. This accounted for 36% of the readback errors found in this study. Errors involving radio frequencies accounted for 26% of the errors. Errors involving altitudes accounted for 17% of the errors, and errors involving speed accounted for 12% 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
Heading	29	36%
Frequencies	21	26%
Altitude	14	17%
Speed	10	12%
Other	7	9%
Total	81	100%

Clearly, ATC instructions are numerically intensive. A common type of error involves transposing numbers in a message, either individually or as a group. In the following example, the pilot confused two groups of numbers - the speed with the heading. “Fly heading three one zero and reduce *speed to two one zero*” was read back as, “Ok, *three ten on the speed, two ten on the heading*”. In this particular example, the controller missed the readback error. The clean transposition and the fact that both numbers ended in “ten” probably contributed to the likelihood of this hearback error. It is even more common to transpose individual numbers, as in the following example. The clearance to “Change runway to **two** five left, cross [location X] at or above seven thousand, maintain **three thousand** five hundred” was read back as “Cross [location X] at or above seven thousand, maintain **two thousand** five hundred, [aircraft call sign]”.

The fact that this study revealed more readback errors involving headings than radio frequencies was puzzling. In the en route environment, readback errors involving radio frequencies were more common than any other instruction. It makes sense that pilots would (either consciously or not) put more mental effort into remembering an altitude or heading than a radio frequency. It is much easier (and less painful for all involved) to go back and get the correct frequency than to bust an altitude or fly off course. This puzzling finding of readback errors involving headings being more prominent than errors involving frequencies prompted a secondary analysis.

The number of readback errors were compared to the total number of readbacks of controller transmissions containing that type of information. For example, there were 31 readback errors involving aircraft headings. There were 3,396 readbacks of headings. Therefore, the percentage of readback errors was .8%. Table 3-5 lists the proportion of readback errors to the total number of readbacks containing that type of information. This analysis showed that **readback errors involving radio frequencies are more probable than any other type of information and readback errors involving altitude are the least likely** (given the number of clearances issued with this type of instruction). In fact, in this relative sense, readback errors of frequency information were more than twice as likely as those involving altitude clearances. To summarize, in this analysis readback errors involving heading and altitude were more common than those involving speed and frequencies. However, this was due to the fact that there were many more instructions issued involving heading and altitude than those involving speed and frequencies. After all, instructions to change radio frequencies is only issued to each aircraft only once in a given sector.

TABLE 3-5. PROBABILITY OF A READBACK ERROR AS A FUNCTION OF TYPE OF INFORMATION

Type of Information	Number of Readback Errors	Percent of Readbacks in Error
Radio Frequencies	21	1.1%
Speed	10	1%
Heading	29	.8
Altitude	14	.4

It should be noted that even a correct readback does not ensure that a pilot/aircraft will perform as expected. In one recorded case (and no doubt many others), the pilot read back the correct frequency, but dialed it in wrong. This was evident in the tape analysis when the pilot called back to get the frequency again.

3.3.3 Hearback Errors

There were thirty-two instances in which the controllers did not notice the error in the pilot's readback. This means that 40% of the readback errors also resulted in hearback errors. As Table 3-6 shows, controllers were most likely to catch readback errors involving altitudes and radio frequencies (perhaps because the controller routinely assigns the same ones) and least likely to catch readback errors of heading instructions. Controllers caught 79% of the readback errors involving altitudes, and 74% of the readback errors of frequencies. They corrected approximately half of the readback errors of headings (55%) and speed (50%).

TABLE 3-6. PERCENTAGE OF HEARBACK ERRORS BY TYPE OF INFORMATION

Type of Information	Number of Readback Errors	Number of Hearback Errors	Percentage of Hearback Errors
Frequencies	21	5	24%
Altitude	14	3	21%
Heading	29	16	55%
Speed	10	5	50%
Other	7	3	43%

In addition to these hearback errors, there was also one instance of a different type of listening error. In this case, the pilot requested that the controller repeat the heading, but the controller repeated the frequency instead. This miscommunication then escalated as the foreign pilot then interpreted part of the frequency for the heading. The controller caught this error and resolved the misunderstanding with a single additional transmission.

3.3.4 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 read back *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 127 instances (1% of the messages) of pilots requesting that a controller repeat all or part of the transmission. Most (60%) of these were requests for a partial repeat and the remainder (40%) were requests for a repeat of the entire transmission (e.g., “say again?”).

3.3.5 Pilot Report of Altitude Information

Since altitude deviations are a particularly hazardous potential result of a communication error, other communication practices related to altitude were also examined.

Initial Check-in. When checking onto a new frequency, 49% of the pilots reported both the altitude they were at (or passing through) and their newly assigned altitude. An additional 39% percent reported their current altitude. Four percent reported their newly assigned altitude without also reporting their current altitude. Finally, only eight percent checked in without reporting any altitude.

Responses to Altitude Clearances. When issued a new altitude clearance (i.e., not including instructions to maintain current altitude), 85% of the pilots readback the new altitude (only). Twelve percent of the pilots readback both the altitude they were leaving and their newly assigned altitude, and three percent reported the altitude they were leaving, but not their newly assigned altitude.

Altimeter settings. Another opportunity for error is a misset altimeter. In a study of altitude deviations, a few of the cases were due to one or both altimeters being off by 1,000 feet because “the pilots only checked the last two digits when resetting at the FL180 transition altitude and the actual pressure called for checking three digits rather than two (e.g., 29.92 and 28.92)” [MiTech, Carlow and FAA, 1992, p.2-4-16]. In the current study, only 52% of the altimeter setting issued by a controller were even partially read back. Of course, every altimeter setting issued by a controller was given with all four digits. However, only 74% of the pilots' readbacks of this information contained four digits. Ten percent of the readbacks had three digits (in only two percent of these cases was the last digit a zero), and 14% of the pilots read back only the last two digits.

3.3.6 Call Sign Discrepancies

Problems involving aircraft call signs have been studied in-depth using reports from the Aviation Safety Reporting System (ASRS) by Monan (1983). Monan's report documents that abbreviated, missing, or similar sounding, call signs - as well as other communication difficulties involving aircraft call signs - has lead to: altitude deviations, aborted take-offs, runway incursions, descents toward terrain, and other problems. Fortunately, these types of problems are too rare to be observed in 48 hours of voice tape analysis. What is not as uncommon are instances where pilots and controllers respond to one another using different call signs.

There were 79 instances (.8% 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. There were a few aircraft that had multiple instances of call sign discrepancies. That is, there was more than one exchange between the controller and pilot where they each used a different call sign. These multiple instances (involving the same aircraft) were counted as one, no matter how many occurrences there were. Table 3-6 shows the types of information contained in these transmissions involving call sign discrepancies. Forty-eight percent of these transmissions contained altitude clearances, 42% of these transmissions contained instructions to change heading, 18% of these transmissions contained instructions to change frequencies, and 9% of these transmissions contained speed instructions. (Since most controller transmissions contained more than one piece of information, these percentages add up to more than 100.) Only 47% of these call sign discrepancies were corrected. Approximately one-half (53%) 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. Sixty-seven percent of these call sign discrepancies involved Part 121 and Part 135 carriers. This percentage of call sign discrepancies that remain uncorrected is similar to what was found in other environments: 61% of the call sign discrepancies in the en route environment were uncorrected (Cardosi, 1994), as were 56% of the call sign discrepancies in ground control communications (Burki-Cohen, 1995) and 52% of the discrepancies in the tower communications (Cardosi, 1993).

Both controllers and pilots are responsible for call sign discrepancies. In the majority of instances that were not corrected, it is impossible to determine who was using the wrong call sign. In the remainder of cases, however, we can examine transmissions that preceded and came after the instance to see whether it was the pilot or the controller who changed the call sign that they were using to conform to the call sign used by the other. In 79% of these cases, where one party changed the call sign they were using, the controllers changed the call sign they had used to conform to what the pilot had used. In 21% of these instances, the pilots changed the call sign to what the controller had used. (In a few cases, the pilots either stopped using a call sign on subsequent transmissions or used a partial call sign that was different from what the pilot had used previously, but was compatible with what the controller was using.²) It is not easy for airline pilots to keep track of their call signs (without posting it somewhere in the cockpit), since their call signs are likely to change several times a day. It is even easier for controllers to occasionally confuse the endless series of alphanumerics that are critical to their tasks.

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 presents obvious opportunities for errors, 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, or other types of communication errors.

3.3.7 Wrong Aircraft Accepting a Clearance

In addition to the readback errors and call sign discrepancies there were seven instances of the wrong aircraft responding to a clearance. All seven of these potentially quite serious errors were caught by the controllers and rectified. In one of these instances, there was a stuck mike on the frequency for two and one-half minutes that led to an unintelligible transmission that led to the error. In two other instances two aircraft had the same company name. In the remaining instance, there was no identifiable factor that contributed to the error. However, in many of these types of cases, it is usually the case that pilots erroneously accept a clearance that they have been expecting (or hoping for).

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, foreign pilots who have a poor grasp of the English language, similar call signs, and blocked transmissions as contributing

2. For example, the controller used "Air Carrier 1642." The pilot previously used "AirCarrier 1842," but subsequently responded with "42, Roger."

factors. Voice tape analysis cannot provide much insight into 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 with the miscommunications:

- 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 miscommunications (call sign discrepancies, readback errors and pilot requests for repeats) was examined for the coincidence of these factors. That is, if any one of these factors was present in a miscommunication, it was noted. This does not necessarily mean 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. The only coincident factors seen in any of the miscommunications in this analysis were: similar call signs on the same frequency, a stuck microphone leading to blocked communications and a foreign pilot. Similar call signs were coincident with 6% of the miscommunications. Blocked transmissions due to a stuck mike on the frequency for 2 1/2 minutes led to the wrong aircraft accepting a clearance. A foreign pilot had trouble understanding the controller and asked the controller to repeat the heading. When the controller mistakenly repeated the frequency instead, the pilot said, "I am a German pilot, please speak slowly and repeat". The controller then repeated the frequency again, and the pilot read back three of the numbers in the frequency as the heading. The controller caught this error and corrected the misunderstanding with a single transmission. Bad weather, equipment malfunctions, pilot's or controller's use of nonstandard phraseology, rate of speech, and controller 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 properly 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 was only a single incident of a communication error being directly attributable to blocked transmissions in the 48 hours of tape examined. Still, the consequences of a stuck microphone in busy airspace can be even more serious than what occurred in this instance (i.e., the wrong aircraft accepting a clearance). The fact that none of the factors examined were found to have

significant effects is not meant to suggest that problems do not exist - each specific type of problem merits individual study.

3.3.9 Miscellaneous

This tape analysis also revealed some interesting examples of pilot and controller communication behaviors that are worth considering. It is important to keep in mind that this tape analysis was not designed to study these types of instances and so, it cannot provide **any** information on how prevalent they are. However, they are worth mentioning because they point to potential problem areas - and one success.

Poor Microphone Technique. There were several instances where part of the readback was clipped, leaving it ambiguous as to whether or not the pilot received the correct information. For example, "... turn right heading three six zero" was read back as "six zero [call sign]".

Nonstandard Phraseology. Use of nonstandard phraseology can lead to serious ambiguities in communication. For example, "...descend and maintain one one thousand, expect runway eight" was read back as "OK, one one thousand and down to eight". While the pilot probably understood the "eight" to refer to the runway and not an altitude, this is not clear from the readback.

"Until Established on the Localizer". The Altitude Awareness Study (MiTech, Carlow and FAA, 1992) found that "established on the localizer" means different things to pilots and controllers. "To pilots, it means as soon as their equipment indicates that they've hit the localizer beam, while to controllers it means that the aircraft is fixed and tracking on the localizer centerline." (p. 2-4-16). This is such a commonly used phrase, that if this misunderstanding still exists, it should be rectified.

"We've Got 'em on TCAS". When controllers point out traffic to pilots or ask pilots if they have the traffic in sight, pilots sometimes respond that they have the traffic on TCAS (Traffic Alert and Collision Avoidance System). However, pilots and controllers may not realize that the bearing accuracy of the current TCAS systems is not sufficient to support a maneuver in these types of situations (e.g., in the terminal area). Also, until TCAS can identify a particular aircraft, there is always the possibility that the aircraft displayed on TCAS is not the aircraft that the controller pointed out. Therefore, in these situations, the value of having the aircraft on TCAS without visual acquisition (i.e., out the window) is questionable.

Four Ears are Better than Two. At least one hearback error was prevented when a controller issued a clearance to "turn right heading zero **eight** zero, join J one twenty-eight, resume own navigation". The pilot read back "a right turn zero **six** zero to join the airway, [aircraft call sign]". The next transmission is from the same aircraft, "Well, I guess I need to confirm that uh the heading for [aircraft call sign] was zero **eight** zero". It's possible that the pilot had second thoughts about what he heard. Its more probable that these second thought were induced by another person in the cockpit. Good CRM (Cockpit Resource Management) can go a long way to catching and correcting errors before they have any ill effects.

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.

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, pilots would like to require a higher standard of information processing from them - i.e., to catch every readback error - just as controllers would prefer that pilots always heard what the controller said, rather than what the pilot expected to hear. 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. Perhaps, erroneous readbacks should be routinely included in the traffic scenarios used in controller training, as a recent ASRS report suggests (ASRS Callback, 1992).

Since there is always room for improvement, the following are recommended pilot and controller actions that can further improve the efficiency of voice communications. Pilots should be encouraged to:

- be conscientious about their microphone technique so that their transmissions are not clipped,
- ask for clarification, rather than expect the controller to catch readback errors,
- be diligent about using full call signs to acknowledge controller transmissions,
- question call sign discrepancies (as in “... Was that for Air Carrier 123?”), and
- read back the full clearance whenever practical.

Controllers should be encouraged to:

- keep their transmissions brief,
- listen for the call sign, as well as the content, of the pilot's readback and question any discrepancies
- actively listen for readback errors, and
- 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, and the fact that they are on the same frequency and should be announced. The same is true for same airline flight numbers that differ only by one digit, or one syllable, as in the case of “two” and “ten”.

Finally, controllers and pilots need to use the standard phraseology that was designed for unambiguous communication. They should also have a common understanding of key operational information (e.g., such as the abilities and limitations of TCAS, the limitations of the weather information displayed to controllers, etc.). 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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