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# PILOT ERROR IN COPYING AIR TRAFFIC CONTROL CLEARANCES

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A study investigating the accuracy of pilots' copying air traffic control clearances is described. Twenty-four airline pilots listened to 28 taped clearances and copied them down on an answer sheet using shorthand, longhand, or some combination of these according to their preferences. The copied clearances were analyzed by the number of correctly copied elements, the number of omitted elements, and the number of extraneous elements that were not present in the original clearance. Preliminary results indicate a strong influence of habit and familiar operating environment and procedures on the accuracy of copying unfamiliar information. Common errors included victor-airways copied as jet-airways, low altitudes copied as much higher, and slow speeds copied as much higher. The vulnerability of controller-pilot communications to the effects of unfamiliarity is apparent. A detailed analysis of these data may provide for a better understanding of the shortcomings of controller-pilot communication.

## INTRODUCTION

Means of communication between pilots and controllers is one of the fundamental principles of air traffic control (ATC) (Hopkin, 1995). The essential format of ground-to-air communication is the air traffic clearance, which is defined in the pilot/controller glossary as "an authorization by air traffic control, for the purpose of preventing collision between known aircraft, for an aircraft to proceed under specified traffic conditions within controlled airspace" (FAA, 2000). To overcome the many threats to reliable communication, such as noise, language problems, and controllers' and pilots' expectations, biases, and other cognitive factors, the language, phraseology, and procedures used in pilot—controller communication are highly regulated (e.g., FAA, 2000). Hence, air traffic controllers issuing clearances to pilots are required to adhere to extensively standardized content and structure, the pilots are required to read back their clearances verbatim to the controller, who in turn are required to verify through hearback that the pilot indeed had received the clearance correctly. Finally, the controller must acknowledge correct hearback either explicitly to the pilot or implicitly by not correcting the readback. Assurance of accurate communication is hence a three-step process.

Although these procedures form the primary safeguard against the ATC system failures, they also pose a considerable load on both pilots' and controllers' working memory (Loftus, Dark, & Williams, 1979). To reduce their respective efforts in communication, controllers and pilots often resort to shortcuts and deviations from prescribed procedures. Controllers may increase their speech rate and produce long messages with multiple elements to reduce the total number of transmissions and pilots may abbreviate their readbacks (Morrow, Lee, & Rodvold, 1993). However, such strategies entail a high risk of erroneous readbacks, requiring corrections by controllers and engagement in nonroutine communications, effectively miscarrying the original objectives. Indeed, communication problems have frequently been cited as contributing factors in operational errors, pilot deviations, and near midair collisions (Prinzo, 1996). It has also been shown that long clearances increase the frequency of erroneous readbacks and that clearances that combined different pilot responses also resulted in communication problems (Morrow, Lee, & Rodvold, 1993).

In the cockpit, reception, acknowledgement, and compliance with ATC clearances is but one of the pilots' many concurrent tasks. To mitigate the transitory nature of voice communication and to be able to refer back to the clearance either because other cockpit activities prevented immediate compliance or because the clearance pertained to a later phase of the flight, pilots routinely write down the clearance using shorthand notation. The study of ATC clearances as copied by pilots offers therefore a potentially very constructive way to investigate the reliability of the first stage of controller-pilot communication, that is, how accurately pilots can receive their clearances. In particular, such a study would reveal how well the pilots' expectations and mental models of the clearance content and structure facilitate accurate copying of the clearance on one hand, and what might be some of the most common errors controllers should be aware of when issuing clearances on the other.

This paper presents a subset of a much larger study involving a total of 345 subjects from a major U.S. airline and two large university flight schools to investigate the accuracy of pilots' copying of ATC clearances. The results reported here are therefore limited to the subject group specified below. Correspondingly, the conclusions should also be viewed as tentative.

## METHOD

### Subjects

The subjects were experienced line pilots with a major U.S. air carrier. The mean total experience was 4,160 hours, with a range from 2,300 to 6,500 hours. The mean pilot-in-command experience was 2,564 hours with a range from 1,400 to 4,200 hours. Fourteen out of a total of 24 subjects participating in the study were also experienced in the use of FMS.

### Stimuli

Twenty-eight different ATC clearances were recorded. The clearances ranged from very simple, with only two elements, to complex, with up to ten elements. The average number of elements in a clearance was 4.32. An element is here defined as a separate part of the clearance that specifies a distinct action the pilot needs to take or a limitation the pilot needs to observe. Hence, a clearance "…cross DINGO INTERSECTION at or above five thousand feet" contains two elements: The intersection and an altitude restriction. In addition to the number of elements, the complexity of the clearance also depended on the mixing of various elements in it. The simplest clearances contained elements pertaining only to navigation or altitude, whereas complex clearances contained a mix of navigational, altitude, speed, and time information.

### Procedure

The purpose of the experiment and their task were explained to the subjects. They then listened to the prerecorded clearances and wrote them down on an answer sheet using either long- or shorthand or some combination of these according to their individual preferences. The subjects heard the clearance only once. They were not given the opportunity for a readback or to ask for clarification, or to take any actions on the clearances. This method was used to force the subjects to capture only the most important elements in the clearance.

## RESULTS

### Data Reduction and Analysis

There are numerous ways to analyze air-ground communications (Prinzo, 1996; Prinzo & Britton, 1993, 1994; Prinzo, Britton, & Hendrix, 1995). Air-ground communication can be coded and classified according to speech acts (Morrow, Cark, Lee, & Rodvold, 1990; Searle, 1969) or as elements (e.g., Cardosi, 1993). It might also be argued that the action verb (e.g., "climb," "maintain," "fly," or "turn") and the object (e.g., altitude or heading) should be coded separately. Although clearances "fly heading…" and "turn left heading…" are clearly different, we adopted the view that the primary element in the clearance was the heading, and the necessary action (i.e., direction of the turn) was implicit in it and hence separate coding was not warranted. Therefore, for the purposes of this study, the data reduction, coding, and analysis followed the definition of clearance element as stated earlier.

The clearances were analyzed according to the type (e.g., altitude, navaid, heading, etc.) of elements in them as well as the sequence of the elements and the overall complexity of the clearance. The clearances copied on the answer sheets were evaluated against these criteria by tallying the correctly copied elements, their sequence, and by two types of errors, errors of omission and errors of commission. Errors of omission were simply omitted information (e.g., an airway was read in the clearance but not copied down). These errors also include instances where, for example, the word "VOR" was written down but the name of the navaid was missing. Errors of commission included information that was not present in the clearance but that was copied down nevertheless. Examples of such errors are extra airways copied that were not in the clearance, incorrect numbers, and incorrect navaid or airway names. The number of errors of each type were averaged across the subjects and compared to the corresponding clearance.

The errors were analyzed according to the complexity of the clearance. Clearances were ranked according to their complexity, 1 representing the simplest clearance and 28 the most complex (see Table 1). This ranking was based on the number of elements in the clearance, whether the clearance mixed different kinds of elements (e.g., navigational information with altitude or speed) and whether the clearance was congruent or not (i.e., the order of elements in the clearance corresponded to the progression of the flight).

Furthermore, the order of clearance elements in the copy was analyzed to examine whether the pilots adhered to the original sequence of elements in the clearance or sought to copy the clearance in a different order, perhaps better corresponding to their tasks in the cockpit.

**Qualitative Analysis and Descriptive Statistics**

The most striking result was the very high number of a few errors of particular type: The pilots frequently copied victor-airways as jet-airways, low altitudes as much higher (e.g., 5,000 ft was often copied as FL 150), and slow speeds as much higher (e.g., 100 kts copied as 200 or 300 kts). None of these errors seemed to correlate with the complexity of the clearance itself; for example, all subjects made such errors in one particular clearance, which only had two elements! The results are therefore skewed by the number of airway-, altitude-, and speed-related elements in the clearance, which may obscure the effects of clearance complexity and other factors.

However, the above results reveal an interesting pattern in the pilots' abilities to accurately copy down a spoken clearance. It is apparent that the subjects were used to an operating environment that was substantially different from the environment depicted in the clearances. The subjects were airline pilots, flying predominantly passenger jets or high-performance turboprops at flight levels and along jet-airways, while the clearances used in this study pertained to altitudes and speeds in the general aviation domain. Furthermore, the subjects, who flew mostly in the Midwest, were presumably unfamiliar with the geography portrayed in the clearances, which were set in the Southwest. It was indeed startling to see in the data how pervasive familiar environment and procedures can be, even in a task performed in a laboratory environment with only remote connections to a cockpit situation. This could also attest to carelessness from the subjects' part.

The results are summarized in Table 1. There is no apparent correlation between the number of elements or complexity rank and percent of correctly copied elements. The same is true for both types of errors (omission and commission). What is noteworthy, however, is the much larger number of errors of commission than errors of omission. This may suggest that the pilots were eager to just write something down with apparently little regard to the correctness of the information.

Table 1.
*The average number and percentage of correct elements, errors of omission, and errors of commission for each clearance. The data are arranged by percentage of correctly copied elements. Clearances were ranked by their complexity, 1 representing the simplest clearance and 28 the most complex..*

| Clearance Number | Number of Elements | Complexity Rank | Mean Number of Correct Elements (%) | | Mean Number of Errors of Omission (%) | | Mean Number of Errors of Commission (%) | |
|---|---|---|---|---|---|---|---|---|
| 25 | 3 | 9 | 3.00 | (100.00) | 0.00 | (0.00) | 0.00 | (0.00) |
| 27 | 2 | 1 | 2.00 | (100.00) | 0.00 | (0.00) | 0.00 | (0.00) |
| 23 | 2 | 8 | 1.92 | (95.83) | 0.04 | (0.52) | 0.04 | (0.52) |
| 6 | 4 | 20 | 3.79 | (94.79) | 0.08 | (0.42) | 0.13 | (0.63) |
| 10 | 8 | 26 | 7.33 | (91.67) | 0.42 | (1.60) | 0.25 | (0.96) |
| 28 | 7 | 21 | 6.33 | (90.48) | 0.29 | (1.39) | 0.08 | (0.40) |
| 15 | 5 | 23 | 4.50 | (90.00) | 0.46 | (1.99) | 0.04 | (0.18) |
| 16 | 3 | 4 | 2.46 | (81.94) | 0.42 | (10.42) | 0.17 | (4.17) |
| 2 | 3 | 14 | 2.38 | (79.17) | 0.54 | (3.87) | 0.08 | (0.60) |
| 11 | 7 | 24 | 5.46 | (77.98) | 0.25 | (1.04) | 1.25 | (5.21) |
| 3 | 4 | 19 | 2.96 | (73.96) | 0.29 | (1.54) | 0.75 | (3.95) |
| 17 | 5 | 16 | 3.63 | (72.50) | 0.29 | (1.82) | 1.04 | (6.51) |
| 14 | 4 | 18 | 2.88 | (71.88) | 0.04 | (0.23) | 1.08 | (6.02) |
| 19 | 4 | 7 | 2.83 | (70.83) | 0.17 | (2.38) | 1.00 | (14.29) |
| 8 | 3 | 6 | 2.13 | (70.83) | 0.04 | (0.69) | 1.17 | (19.44) |
| 20 | 5 | 17 | 3.46 | (69.17) | 0.50 | (2.94) | 1.04 | (6.13) |
| 7 | 3 | 5 | 2.04 | (68.06) | 0.04 | (0.83) | 0.92 | (18.33) |
| 22 | 3 | 11 | 1.96 | (65.28) | 0.00 | (0.00) | 1.00 | (9.09) |
| 18 | 3 | 3 | 1.92 | (63.89) | 0.08 | (2.78) | 1.00 | (33.33) |
| 13 | 10 | 28 | 6.38 | (63.75) | 0.75 | (2.68) | 2.71 | (9.67) |
| 5 | 4 | 22 | 2.54 | (63.54) | 0.17 | (0.76) | 1.00 | (4.55) |
| 9 | 8 | 27 | 4.75 | (59.38) | 0.29 | (1.08) | 2.79 | (10.34) |
| 24 | 2 | 13 | 1.00 | (50.00) | 0.00 | (0.00) | 1.00 | (7.69) |
| 4 | 2 | 10 | 0.96 | (47.92) | 0.04 | (0.42) | 1.00 | (10.00) |
| 1 | 8 | 25 | 3.75 | (46.88) | 0.50 | (2.00) | 3.71 | (14.83) |
| 26 | 2 | 2 | 0.92 | (45.83) | 0.08 | (4.17) | 1.04 | (52.08) |
| 21 | 5 | 15 | 1.92 | (38.33) | 0.04 | (0.28) | 3.04 | (20.28) |
| 12 | 2 | 12 | 0.00 | (0.00) | 0.08 | (0.69) | 1.92 | (15.97) |

The data were also examined by the element in the clearance. Percentage of errors of omission (missing elements in the copy) and commission (erroneously copied elements) were computed by averaging the error tallies across subjects and clearances (Table 2)

Several observations can be made from these data. First, the disproportionate number of errors of commission compared to errors of omission is again evident. Second, the data are apparently skewed by the subjects' propensity to replace victor airways with jet-airways and copying of altitudes and speeds as much higher than in the clearance. Looking beyond these aspects of the data, it is also apparent that elements such as "expedite" or "expect further clearance" (EFC) were frequently omitted.

Table 2.
*Percentages of errors of omission and commission (in descending order) by clearance elements. The top six erroneously copied (error of commission) elements reflect the fact that the subjects copied V-airways as J-airways and frequently added 10,000 feet to altitudes and 100-200 kts to speeds.*

| **Clearance Element** | % Errors of Omission | **Clearance Element** | % Errors of Commission |
|---|---|---|---|
| Expedite | 30.56 | Airway 1 | 91.32 |
| EFC/Other | 13.33 | Altitude 1 | 69.87 |
| Radial 2 | 12.50 | Airway 3 | 63.89 |
| Direct | 9.52 | Speed | 63.89 |
| Hold-Dst | 8.33 | Airway 2 | 62.50 |
| Heading 2 | 6.25 | Altitude 2 | 33.33 |
| Navaid 2 | 5.56 | Hold-Rdl | 22.22 |
| Hold-Dir | 5.21 | Radial 2 | 16.67 |
| Altitude 2 | 4.17 | Radial 1 | 10.00 |
| Heading 1 | 4.17 | Hold-Alt | 8.33 |
| Hold-Alt | 4.17 | Distance | 6.25 |
| Hold-Rdl | 4.17 | Hold-Dst | 6.25 |
| Limit | 2.88 | Direct | 5.95 |
| Airway 1 | 2.78 | Heading 1 | 4.17 |
| Airway 2 | 2.78 | Navaid 3 | 1.39 |
| Navaid 3 | 2.78 | EFC/Other | 1.25 |
| Distance | 2.08 | Hold-Dir | 1.04 |
| Radial 1 | 1.67 | Navaid 2 | 0.46 |
| Airway 3 | 1.39 | Heading 2 | 0.00 |
| Navaid 1 | 1.22 | Limit | 0.00 |
| Altitude 1 | 0.64 | Navaid 1 | 0.00 |
| Speed | 0.00 | Expedite | 0.00 |

Before examining the order of elements in copied clearances compared to the original ones the data were corrected for omitted elements. There was no evidence of any patterns in the order of elements copied, however.

**Inferential Statistics**

The data were analyzed by Analysis of Variance (ANOVA) separately for percent of correct responses and percent of both error types by both the number of elements and complexity rank of the clearances. The results of these analyses are mixed. Although the differences between clearances based on their complexity and the number of elements versus percent correct and percent both error types were statistically significant ($\alpha < .05$ for all but percent omissions versus number of elements, where $p = .078$), these results were clearly due to disproportionate number of errors on a few particular clearances and clearance elements, as can be seen in Tables 1 and 2. For example, all but two subjects copied both elements in a clearance "…descend to eight thousand when established on Victor six four" wrong. Very large between-subjects differences on other clearances contribute to the inconclusiveness of these results, too.

Finally, the effect of pilots' experience on their clearance-copying performance was examined. The pilots were assigned to four groups based on their total flight experience: group one consisted of pilots with between 2,300 and 3,300 hours ($n = 224$), group two of pilots between 3,300 and 4,300 hours ($n = 140$), group three of this between 4,300 and 5,300 hours ($n = 168$), and group 4 of pilots with over 5,300 hour of experience ($n = 140$). Results of ANOVAs on percent correct and both types of error were significant ($p < .001$). However, pairwise comparisons (Tukey's test) revealed that only the most experienced group copied a larger proportion of the clearances correctly and committed fewer errors than the three less experienced groups.

## DISCUSSION

Hand-copied ATC clearances provide a potentially very rich source of data about pilots' abilities to accurately copy clearances for readback or later reference. Although a copy of a clearance is an invaluable aid to support the pilots' working memory in a very demanding environment, performing this task sufficiently well is apparently very difficult. Analysis of errors, possibly preferred order of copying, and the pilots' ability to copy the most important elements in the clearance may provide for a better understanding of the vulnerabilities of controller-pilot communication and suggest guidelines for improvement of reliability of air-ground communication systems.

This study uncovered many issues relevant to both pilots' task of hand-copying clearances and analysis of such data that must be carefully considered before further—and firmer—conclusions can be made, however. The clearances used in this study were very realistic and similar to those commonly encountered by pilots all around the world. Because of their realism, however, it was difficult to extract clearly defined independent variables from the stimuli. On the other hand, carefully patterned stimuli would necessarily be simplistic and results consequently difficult to generalize to operational settings.

The experimental situation was obviously far removed from the cockpit environment and the many concurrent tasks pilots need to perform. It is difficult to say what impact this might have had on the astonishingly poor performance of the very experienced subjects. On one hand, it can be argued that listening to a good quality tape recording in a quiet laboratory should have resulted in a near-perfect performance. On the other hand, the subjects were deprived of the many cues available in a cockpit environment in flight, and it is plausible that the navigational, altitude, and speed information made little sense to them outside the context, contributing to the number and types of errors observed in the data.

## CONCLUSION

The data presented in this paper were a subset from a larger study involving a total of 345 subjects with varying experience and background. Nevertheless, some initial conclusions can be made from the limited analyses reported here. It is apparent that the number of elements in a clearance is not alone a sufficient predictor of accuracy of a copy. Some clearances with very few elements had a much larger proportion of errors than longer clearances. It is also clear that complexity of a clearance is very difficult to define. As defined in this study, a complex clearance could be copied much more accurately than a simple one, as was shown by these data. Presumably, pilot expectancy of a clearance will have a significant impact on how accurately the clearance is received; it is unclear, however, what role expectancies might have played in this study.

The obvious limitations in this study were a relatively small number of subjects (24) and the potential mismatch between their experience (airline) and the contents of the sample clearances (general aviation). Analysis of the complete data set will likely help answer many of the questions discussed above and provide a better picture of plots' clearance-copying performance.

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