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The Outcome of ATC Message Complexity on Pilot Readback Performance

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16. Abstract

Field data and laboratory studies conducted in the 1990s reported that the rate of pilot readback errors and communication problems increased as controller transmissions became more complex. This resulted in the recommendation that controllers send shorter messages to reduce the memory load imposed on pilots by complex messages. More than 10 years have passed since a comprehensive analysis quantified the types and frequency of readback errors and communication problems that occur in the operational environment. Hence, a content analysis was performed on 50 hours of pilot and controller messages that were transmitted from 5 of the busiest terminal radar approach control facilities in the contiguous United States between October 2003 and February 2004. This report contains detailed and comprehensive descriptions of routine air traffic control (ATC) communication, pilot readback performance, call sign usage, miscommunications, and the effects of ATC message complexity and message length on pilot readback performance. Of importance was the finding that both the number of pilot requests and readback errors increased as the complexity and number of aviation topics in ATC messages increased — especially when pilots were performing approach tasks as compared with departure tasks. Also, nonstandard phraseology associated with a lack of English language proficiency and international communications were present in the data. In particular, pilot use of the word "point" as part of a radio frequency was included in the read back of altitude ("three point five") and speed ("two point seven on the speed"). To limit the occurrence of communication problems and misunderstandings, controllers should be encouraged to transmit shorter and less complex messages. With increases in international travel, areas of concern related to English language proficiency and language production need to be addressed.

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EXECUTIVE SUMMARY

The results presented in this report provide a description and summary of the controller-pilot communication process that occurred during normal, day-to-day operations in the terminal radar approach control (TRACON) environment. On average, across the five sampled TRACON facilities, one aircraft requested and received air traffic services every 1 min 26 s in the approach sectors and 1 min 6 s in the departure sectors. Approximately 13 messages were exchanged (from initial contact until the aircraft was switched to the next controller in sequence) that involved an allocation of about 1 min 16 s of airtime per aircraft.

A comparison between the voice communications analyzed by Cardosi et al. (1996) with those analyzed here by Prinzo, Hendrix, and Hendrix revealed that more than 50% of controllers' messages were fairly short but information rich. Pilots increased their production of full readbacks — up from 60% in 1996 to more than 82% in 2004. Most striking was the finding that 10 years ago, pilots provided a full readback with a complete call sign about 37% of the time, and in 2004 it accompanied a full readback in 61% of the pilots' transmissions. Where Cardosi et al. (1996) reported that 24% of the full readbacks included a partial call sign, we found 18.8%, of which 13.4% excluded the prefix but included all the numbers/letters of the call sign. Likewise, pilot/controller call sign mismatch has decreased from 0.8% to 0.3%.

Both the Cardosi et al. 1996 report and this report show that aircraft headings and radio frequency changes still are the most frequently occurring readback errors. Likewise, there is no change in the frequency with in which pilots request that controllers repeat all or some portions of their transmissions.

The operational data analyzed in this report provide additional evidence that readback errors and pilot requests increased with increases in message complexity (amount of information in a communication element) and message length (when measured by number of aviation topics such as heading, altitude, speed instructions in a controller's message). Importantly, pilots experienced the most difficulty reading back ATC messages with more than one aviation topic and ATC messages with a complexity value of 10 or greater when flying the approach segment of their flight.

A new trend that is occurring in pilot communications is the tendency to round the numbers in the call sign and aviation topics. For example, Ownship67H became Ownship60H and Ownship528 became Ownship520. Some pilots truncated or otherwise abbreviated the numerical values in speed ("TWENTY FIVE KNOTS"), heading (e.g., "ONE FOUR" for a heading of one four zero), or altitude assignments ("DOWN TO FIVE HUNDRED).

Other forms of nonstandard phraseology were also associated with readback errors. It may be that some of the phraseology used (or heard) by pilots during international flights is making its way into the national airspace system (NAS). Some pilots used the "point" designation associated with radio frequencies when reading back altitudes (e.g., "THREE POINT FIVE" instead of "THREE THOUSAND FIVE HUNDRED") and speeds (e.g., "TWO POINT SEVEN ON THE SPEED" for "TWO HUNDRED AND SEVENTY KNOTS"). Likewise, several pilots flying for foreign air carriers displayed some problems in English proficiency and language production — for example, reading back a speed instruction as "TWO ZERO HUNDRED" instead of "two hundred knots," or responding to "maintain visual from traffic" as "MAINTAIN VISUAL APPROACH."

Communicating for safety is the primary objective of the phraseology developed for and provided in *FAA Order 7110.65, The Handbook of Air Traffic Control* for controllers and the *Aeronautical Information Manual* for pilots. With increased international travel and the gradual migration of other phraseologies into the NAS, pilots and controllers must remain vigilant in the accurate production and recitation of ATC clearances, instructions, advisories, reports, requests, and other communications.

THE OUTCOME OF ATC MESSAGE COMPLEXITY ON PILOT READBACK PERFORMANCE

"Speak properly, and in as few words as you can, but always plainly; for the end of speech is not ostentation, but to be understood."

—William Penn, English religious leader and colonist (1644–1718)

As stated in the Federal Aviation Administration (FAA) *Flight Plan 2006-2010* report (2006), the FAA's mission is to provide the safest, most efficient aerospace system in the world. In the aftermath of 9/11, it is not surprising that the number of passengers and scheduled air carrier flights decreased. Since the implementation of changes in airport and aircraft security, consumer confidence has gradually returned, and the number of scheduled flights and passenger volume are at pre-9/11 levels. For example, in the year 2003, there were 120.5 million aircraft operations recorded. For the first time in several years, some of the busiest air traffic control (ATC) towers are again experiencing traffic delays and congestion.

The FAA has met with representatives of the airline industry and ATC facility personnel to resolve these problems. One solution was to reduce the number of departures per hour by developing new flight departure schedules with some of the larger airlines. A second solution was the construction of new runways at these busier airports in expectation of projected increases — the FAA has set a goal of adding an additional 500 flights per day — that is an increase of about 1% per year with an anticipated total civil aircraft activity of 137.4 million operations by the year 2015.

Increases in air travel go hand in hand with increases in the delivery of ATC services. The existing ground infrastructure and analog voice communications system is the medium by which services are delivered. They include the transmission of clearances and instructions as well as traffic and weather advisories. These transmissions are critical for the coordination of all vehicle movement to ensure safety while aircraft are on the ground and when they are in the air.

Unfortunately, at some of the busiest ATC facilities, air-ground and ground-ground communications are at their pre-9/11 saturation points during peak traffic periods. During these times, pilots often compete with one another for access to the same radio frequency to establish contact, receive clearances, make requests, etc. Too many pilots assigned to the same radio frequency can result in communication bottlenecks that can add to airport congestion, delays, and may increase the potential for communication problems.

Sometimes controllers adopt the strategy of sending longer, more complex transmissions in an attempt to reduce the number of times they need to be on frequency, while including all the information required by FAA policy/regulations. As well-intended as the strategy is, field studies (Cardosi, 1993; Cardosi, Brett, & Han, 1996; Prinzo, 1996) and laboratory experiments (Morrow & Prinzo, 1999) have documented that the rate of pilot readback errors and communication problems increased as controller transmissions became more complex. Often, the occurrence of pilot readback errors necessitates the exchange of additional messages to ensure that the intended meaning was received, understood, and confirmed. This process added to radio frequency congestion. The amount of information that pilots can actively read back is constrained by the inherent limitations of their verbal working memory.

Humans have limitations in the amount of information that they can successfully process, store, recognize and recall. At first, a person may form many groups or "chunks" with few bits of information per chunk. With learning and experience, the amount of information that a person can include in a chunk will vary — but the upper limit of verbal working memory is between five to seven chunks at a time. After that, successful recoding diminishes and forgetting occurs. Through experience, we learn to organize or recode sound into progressively larger groups by translating them into a verbal code (Miller, 1956). He provides the following narrative to illustrate the concept of recoding into progressively larger chunks:

> A man just beginning to learn radio-telegraphic code hears each *dit* and *dah* as a separate chunk. Soon he is able to organize these sounds into letters and then he can deal with the letters as chunks. Then the letters organize themselves as words, which are still larger chunks, and he begins to hear whole phrases. I do not mean that each step is a discrete process, or that plateaus must appear in his learning curve, for surely the levels of organization are achieved at different rates and overlap each other during the learning process. I am simply pointing to the obvious fact that the dits and dahs are organized by learning into patterns and that as these larger chunks emerge the amount of message that the operator can remember increases correspondingly. In the terms I am proposing to use, the operator learns to increase the bits per chunk.

For pilots, with the onset of an ATC message, the sounds at the beginning of the message stream enter into a pilot's limited-capacity verbal working memory, where they are processed and temporally stored as phonological representations. That is, acoustically relevant sounds are extracted and encoded into phonemes (i.e., consonant-vowel-consonant clusters) that form syllables (e.g., stress patterns and intonation) that are assembled to create words, phrases, clauses, and other constituents. These representations must be maintained in an active state (rehearsed) otherwise they begin to decay in about 2 seconds (Baddeley, Thomson, & Buchanan, 1975) or be overwritten by incoming information. Furthermore, Baddeley et al. proposed a linear relationship between the number of words correctly recalled and speech rate. Using mathematical modeling, Schweicker and Boruff (1986) found that 95% of the variance in memory span[1] performance for words, digits, and colors was related to the number of items that were spoken in 2 seconds.

Baddeley's (1987) phonological-loop model of verbal working memory has demonstrated that the ability to accurately recall information in the order in which it was originally heard is better for word sequences that have shorter as compared with longer articulatory durations (i.e., the amount of time taken to pronounce the word sequence). This effect holds true when two sets of words are matched in the numbers of phonemes and syllables in each word but differ in mean articulatory durations (Baddeley & Hitch, 1974; Mueller, Seymour, Kieras, & Meyer, 2003).

An utterance's complexity can be derived from its grammatical weight —the amount of information expressed in its constituents as measured by the number of words, syntactic nodes, or phrasal nodes in the constituent (Wasow, 1997). As pointed out by Miller (1956), to be successful at recoding sensory information into chunks that become progressively larger requires automatic recoding; otherwise, as new inputs are being transmitted, they will be sacrificed while attempting to retain the name of the last group.

These findings, classic to cognitive psychology and psycholinguistics, have been applied to aviation. In particular, field and simulation findings (see Prinzo & Britton, 1993 for a review of the literature; Cardosi et al., 1996; and Morrow & Prinzo, 1999) led to the recommendation that controllers should transmit more messages that were less complex, rather than fewer but more complex messages. The rationale was that less complex messages (fewer topics and less information) should not tax pilots' memory to the same extent as longer, more complex ones (more topics and information). Their recommendation, if made policy and implemented, should lead to fewer readback errors and communication problems.

It has been 10 years since a comprehensive analysis has been conducted to quantify the types and frequencies of readback errors and communication problems that occur in the operational environment. It is important to determine whether the aforementioned findings remain representative. Therefore, the purpose of this report is to 1) provide current information regarding routine communication practices, 2) document the types of transmissions that are exchanged between pilots and the certified professional controllers who provide them with ATC services, and 3) record communication problems by type and frequency of occurrence.

Neither the aforementioned studies nor this study considered the impact of other information sources on communication. In particular, information presented on the controller's situational display provides a rich context from which oral communications become meaningful. For example, alphanumeric information located in the data block provides indications of changes in an aircraft's altitude, speed, track, transponder code, runway/approach, etc. as the pilot complies with an ATC transmission. Also spatial information on video map overlays provides airspace information, while primary and secondary radar track data indicate aircraft proximity and geometry. Together, these rich (and often redundant) information sources aid the controller in the decoding, comprehension, and decision-making processes. They can impact several elements of communication, including the decoding of otherwise unintelligible messages, hearback errors, repeated instructions/clearances (with slight modification), and possibly others. To include this visual reference in any study would require correlating the information on the controller's situational display (video) with the voice communication (audio).

This report is similar to Cardosi et al.'s 1996 report in that both reports focus on clearance acknowledgments and miscommunications in response to ATC messages that differ in level of complexity. Both provide a comprehensive analysis of TRACON communications representative of actual operational communication exchanges between pilots and controllers. Where Cardosi et al., examined communications during periods of heavy and moderate workload (as determined by each facility) we examined communications during heavy workloads only (again, as determined by each facility). Both this report and Cardosi et al.'s 1996 report included communication samples obtained from the Dallas-Fort Worth, Los Angeles, and New York TRACON facilities. Cardosi et al. also obtained communication samples from Boston, Denver,

[1] Memory span refers to the number of items (usually words or digits) that a person can hold in working memory. Tests of memory span are often used to measure working memory capacity. The average span for normal adults is 7.

Miami, Phoenix, and Seattle; we obtained samples from Chicago and Atlanta.

The two reports differ primarily in the tabulation of message complexity. That is, the definition of message complexity provided by Cardosi (1993) for the analysis of Air Route Traffic Control Center (ARTCC) communications changed for the analysis of TRACON communications (Cardosi et al., 1996). In an excerpt from the 1993 report, "Complexity level was computed by counting all elements containing information a pilot has to remember, such as taxiways, runways, who to follow, but not items such as aircraft and facility identification, 'Roger,' or salutations. For example, the instruction '(Air-carrier) 3890, (Facility) Ground, give way to the second Dornier inbound, then taxi runway 32 left, intersection departure at Gulf, via outer, Charlie, Gulf' was coded as containing the following eight elements: Give way, Traffic, Runway, Other, Location, Taxiway 1, Taxiway 2, Taxiway 3. Although most of the instructions contained three or fewer pieces of information, over 35 percent contained four or more elements" (p. 5). That definition agreed with Prinzo, Britton, and Hendrix's (1995) concept of the aviation topic.

Message complexity was defined in the 1996 Cardosi et al. report as 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 be considered as an opportunity for error. For example, 'Air carrier 123, heading two five zero' was considered two elements ('heading' and '250')" (p. 3). Cardosi et al. continued with "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." (p. 3).

As presented and used here, the level of complexity of a communication element is defined by each word or set of words transmitted by ATC to the flight deck that contains a new piece of information critical to the understanding of that communication element. As is often the case, a message transmitted by ATC may contain multiple communication elements, and message complexity would be the sum of the values assigned to each one. As noted in Prinzo (1996), communication elements are the fundamental unit of meaningful verbal language. Within aviation communications, communication elements are identified according to their functionality; that is, their purpose, operation, or action (Address/Addressee, Courtesy, Instruction/Clearance, Advisory/Remark, Request, and Non-Codable) and are restricted with regard to their aviation topic (altitude, heading, speed, traffic, route, etc.) (Prinzo et al., 1995).

What we attempted to do was remove as much of the subjective component as possible when counting the level of complexity present in communication elements. As noted in *FAA Order 7110.65, The Handbook of Air Traffic Control* (FAA, 2004), ATC prescribes that controllers use a rigid set of words/phrases. This phraseology tends to narrow the definition and meaning of communication elements. Some of these words and phrases serve as anchors that make the communication element more precise in its interpretation.

Some anchors attach meaning to the numbers present in a controller's message. For example, the significance of "3-5-0" is ambiguous until an anchor word appears with it in the transmission — "3-5-0" can easily be interpreted as a heading, altitude, or speed. Thus, degrees are associated with heading, knots with speed and descend/climb/maintain with altitude. When so used, anchors assist in the interpretation of communication elements and restrict the meaning assigned to aviation topics (ATs). Each anchor was assigned a complexity value = 1 as were numerical values, orientation (left, right, center), and the names of fixes, points, intersections, markers, etc. as determined by the phraseology usage by the controller according to the examples provided in *FAA Order 7110.65.*

Our scoring scheme attempts to reflect the added complexity imposed by communication elements that contain more information by assigning them larger values. This assumption holds, particularly for altitude instructions. For example, altitude instructions such as "three thousand five hundred," "one-zero thousand" and "four thousand" are likely to impose *quantitatively* different loads on working memory. In particular, "three thousand five hundred" takes longer to pronounce and contains more words than "four thousand" (e.g., articulatory loop proposed by Baddeley, 2000) and utilizes more capacity (Miller, 1956). When serial reproduction is required, numerical content that utilizes more resources may be partially or completely omitted or lead the pilot to request a repetition (Morrow & Prinzo, 1999).

To illustrate the difference between the two approaches, consider the ATC transmission presented in Cardosi et al. (1996), "Aircraft XX, change runway to two-five left, cross Santa Monica VOR at or above seven thousand, descend and maintain three thousand five hundred." For Cardosi et al., the transmission contained five pieces of critical information (but they did not illustrate how this value was obtained). We suggest that the transmission contained four aviation topics: an address, an advisory to expect a change in route/position, an instruction involving an altitude restriction, and an instruction to change altitude. The altitude restriction had a complexity value = 5 (cross = 1, point = 1, at or above = 1, numerical value = 1, thousand = 1) and altitude had a complexity value = 6 (descend and maintain = 2, numerical value = 1, thousand = 1, numerical value = 1, hundred = 1). Therefore, for the present example, the transmission had a complexity value = 11. To be consistent with Cardosi et al., we did not include the address and advisory (other than for traffic or altimeter settings) in the computation of complexity values.

METHOD

Materials

Audiotapes. In this report 28 hr 13 min 23 s of approach and 23 hr 56 min 32 s of departure communications were provided by the five busiest TRACON facilities in the contiguous United States. The amount of voice communications varied from as little as 58 min 55 s on one communication sample to as much as 5 hr 13 min 49 s on another. However, each facility was asked to provide 5 hr of approach and 5 hr of departure voice communications for a total of at least 50 hr of recording. Digital Audiotape (DAT) recordings were made at each TRACON facility using the NiceLogger™ Digital Voice Recorder System (DVRS) to record and time-stamp each transmission.

Each DAT contained separate voice records of all communication transmitted on the radio frequency assigned to a particular sector position on the left channel. The right channel contained the Universal Time Coordinated (UTC) time code expressed in date, hour (hr), minute (min), and whole second (s). The NiceLogger™ Digital Voice Reproducer System (DVRS) decoded and displayed time and correlated it with the voice stream in real time.

There were 12-arrival and 11-departure sectors represented on DATs from the 5 highest-level terminal facilities, and the traffic was typical for a level-5 terminal facility. The traffic was primarily air carrier, with some private jets, and a few general aviation pilots flying the Coastal VFR Corridor. All sectors had some foreign carriers. The recordings were made between October 2003 and February 2004. Each facility representative was instructed that DAT recordings were to reflect communications-intensive periods during peak traffic loads (as determined by that facility). For the outbound push, the sampled recordings represented morning (7:30 am), afternoon (12:30 pm), mid-day (4:30) and evening (5:54 pm) departures and early-morning (8:45 am), mid-morning (11:00 am), afternoon (12:00 pm), mid-day (3:00, 5:00 pm) and evening (7:15 pm) arrivals during the inbound rush.

In addition to maintaining separation, a departure controller's duties include: establish radar contact, verify the Mode C, initiate a radar handoff to en route, and make a communication transfer once the handoff is accepted. Communications involve: establish communication with the pilot, establish radar contact, listen to the altitude report and verify the Mode C, vector, issue speed assignment, altitude assignment, route assignment and communication transfer to the receiving controller (usually the en route controller). Arrival controllers sequence traffic to a single runway and transfer communication to the tower. Occasionally, traffic is routed to a parallel runway. Their communications include: initial contact, listen for altitude reported by pilot, altitude assignment, route assignment vectoring, speed assignment, approach clearance, and communication transfer to the tower.

Subject-Matter Experts (SMEs)

The first author had 12 years of experience analyzing pilot-controller communications. The second author, an instrument-rated pilot and former controller, had worked as an FAA Academy instructor for 8 years and had 12 years experience in FAA supervision and management. The third author had assisted the second author in encoding pilot-controller communications for more than 10 years.

A Guide to the Computation of Level of Complexity. Presented in Tables 1 and 2 are excerpts taken from the Instruction Complexity Guide (Appendix A) and the Advisory Complexity Guide (Appendix B). The tables were developed to increase the reliability and consistency of tabulating complexity for typical ATC phraseology usage. The first column presents the aviation topic; column two presents the complexity value. The smaller the value is, the less complex the phrase. Column three presents the phraseology extracted from *FAA Order 7110.65* to support the delivery of that service. In several cases, the phraseology used by the speaker did not appear in *FAA Order 7110.65* (e.g., tight turn, go fast) but was used so frequently that they were assigned values. Capitalized words designate anchors, are fixed in their meaning, and designate the action that the pilot is to perform. The italicized words in parenthesis are qualifiers that vary according to the geographical location and aircraft position.

To determine complexity value, anchors, qualifiers, and excessive verbiage are assigned a value indicative of new information or importance towards understanding an instruction, traffic advisory, and altimeter setting advisory. In most cases, each anchor is counted as one element of complexity. There are several exceptions, however. Some communication elements contain multiple anchors, as is the case "TURN LEFT/RIGHT HEADING (degrees)." The anchor "TURN LEFT/RIGHT" provides the direction of the turn, while "HEADING" indicates the aircraft's bearing.

Also, qualifiers such as the numbers that comprise an altitude must be evaluated according to the phraseology

Table 1. Excerpt from the Complexity Guide for Instruction/Clearance Communication Elements

Aviation Topic	Level of Complexity	Phraseology
Altitude		3=*(altitude) two digits* +THOUSAND 2=*(altitude) one digit* + THOUSAND 3=*(altitude) two digits* + HUNDRED 2=*(altitude) one digit* + HUNDRED *2=(altitude) two digits* *1=(altitude) one digit*
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* HUNDRED *Three* *five*
	5	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *one zero*
	4	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *four*
	*4-8	CONTINUE CLIMB/DESCENT TO *(altitude)*
	*4-8	AMEND YOUR ALTITUDE DESCEND/CLIMB AND MAINTAIN *(altitude)*
	*3-7	AMEND YOUR ALTITUDE MAINTAIN *(altitude)*
	*3-8	DESCEND/CLIMB TO *(altitude)*
	*2-6	MAINTAIN *(altitude)*
	*1-2	(*altitude*, omitted "THOUSAND" "HUNDRED")
Heading	4	TURN LEFT/RIGHT HEADING *(degrees)*
	4	TURN *(degrees)* DEGREES LEFT/RIGHT
	3	TURN LEFT/RIGHT *(degrees)*
	3	DEPART (*fix*) HEADING (*degrees*)
	3	FLY HEADING *(degrees)*
	2	FLY PRESENT HEADING
	2	HEADING *(degrees)*
	1	*(degrees)*

Table 2. Complexity Guide for Advisory Communication Elements

Aviation Topic	Level of Complexity	Phraseology
Traffic	6	TFC *(number)* MILES *(o'clock)* ALT xxxx *(type etc.)*
	6	YOU'RE FOLLOWING *(type) (o'clock) (number)* MILES ALT xxxx
	5	TFC *(number)* MILES *(o'clock)* ALT xxxx
	2	YOU'RE FOLLOWING *(type)*
Altimeter	3	ALTIMETER *(4 digits)*

used by the speaker. That is, the number "three thousand five hundred" was assigned a value of 4 (a value of one for each number and a value of one for each anchor) since it would be more demanding than either one-zero thousand (value = 3) or four thousand (value = 2). Finally, one element of complexity should be added for communication elements that contain excessive verbiage. Excessive verbiage is determined by comparing the utterance of the speaker against the phraseology designated in *FAA Order 7110.65*. If a pilot attempted a verbatim readback of a controller's transmission, then the coding procedures were applied that were used to evaluate the controllers' transmissions.

A Guide to the Classification of Pilot Readback Errors. As used here, a *readback error* is defined as an unsuccessful attempt by a pilot to read back correctly the information contained in the communication elements that comprise the original message transmitted by air traffic control. As seen in Table 3, the column to the left displays the types of readback errors according to a particular type of aviation topic. The aviation topics are heading (HDG), heading modification (HDG MOD), altitude (ALT), altitude restriction (ALT RSTRN), speed (SPD), approach/departure (APCH_DEPTR), radio frequency (FREQ), position/route (RTE), transponder (TRNSPNDR), and altimeter (ALTM).

Many of the readback error types are common to all aviation topics. The more typical ones include errors of substitution, transposition, and omission. Presented in the right column of Table 3 are examples of each type of readback error according to the aviation topic in which it was embedded. Preceding each example of a particular type of readback error is the original ATC message. For example, ATC might transmit the following message to AAL10, "American Ten turn left heading two one zero." If the pilot reads back either "three one zero" or "six zero," it would be coded as a substitution error since the numbers in the original heading instruction included neither a three nor a six.

Some types of readback errors may pose a greater risk to safety than others. For example, transposing a number in an aviation topic may be more of a threat in some situations than the omission of a number or the substitution of an anchor word with its synonym.

Procedure

Data Transcription. One set of audiocassette tapes were dubbed from each DAT and provided to the transcribers who used them to generate the verbatim transcripts. Each message was preceded by its onset and offset time represented in hour (hr) minute (min) and second (s) as it was typed onto an electronic copy of the Aviation Topics Speech Acts Taxonomy-Coding Form (ATSAT-CF; Prinzo et al., 1995). Once the transcribers finished a set of tapes for a TRACON facility, the second and third authors were provided with copies of the transcripts, audiocassette tapes, video maps, air carrier identifiers, and approach/departure routes for use during the encoding process. This process was followed for each of the TRACON facilities.

Message Encoding. The SMEs met on five separate occasions. The first two meetings were used to operationally define message complexity and develop the rules and procedures for encoding each message. This was done to limit the arbitrary and subjective determination of what constitutes information complexity for verbal information. For part of the remaining meetings, the consistency of data encoding was evaluated as the transcripts for each of the remaining TRACON facilities were encoded. This was achieved by having the first and second author randomly encode the same set of 25 messages (for each facility) and then computing the percentage and degree of agreement. In each case, it exceeded 95%.

A follow-on reliability analysis (using Krippendorff's alpha) was performed on 125 different messages after all the data were encoded. Krippendorff's alpha is a reliability coefficient that was originally developed for evaluating agreement between coders performing a content analysis. It is a statistic that is widely applicable wherever two or more methods of processing data are applied to the same set of objects, units of analysis, or items to determine how much they agree (Krippendorff, 1980). Treating the ratings as ordinal data produced an $\alpha = .9898$[2], indicating high inter-rater agreement.

Computation of Level of Complexity for Communication Elements. Each transmission was first parsed into communication elements, labeled by speech act category and aviation topic using the procedures developed by Prinzo et al. (1995). Then the appropriate guide for computing level of complexity (cf. Table 1 and Table 2) was used to look up the appropriate value according to the phraseology used by the controller for that communication element. The value assigned to each communication element was entered into the appropriate column of the encoding spreadsheet.

Like Cardosi et al. (1996), aircraft call sign/facility identification, courtesies, requests, and advisories (except air traffic advisory and the altimeter portion of weather advisory) were excluded. The elements of complexity were counted for the a) instructions/clearances speech acts that involved heading, heading modifier, altitude, altitude restriction, speed, approach/departure, frequency, route, and transponder aviation topics, b) advisory speech act that involved traffic, and c) the altimeter portion of weather advisories.

[2] We thank Andrew F. Hayes for not only developing the SPSS syntax for running Krippendorff's alpha but also for computing it for us.

Table 3. Readback Error Guide Presented by Aviation Topic

Classification of Readback Errors	Examples
Readback Errors Type (HDG)	ATC “AAL Ten turn left heading two one zero”
1 = Substitution of message numbers	1-“three one zero,” or “six zero”
2 = Transposition of message numbers	2-“turn left heading one two zero”
3 = One type of information read back as another type	3-“ two one zero knots”
4 = Incorrect direction of turn	4-“turn right two one zero,”
5 = Omission of one or more numbers	5-“one zero,” “zero on the heading”
6 = Not assigned	
7 = Omission of anchor word(s)	7-“two one zero”
8 = Substitution of anchor word(s)	8-“two hundred and ten degrees”
Readback Errors Type (HDG MOD)	ATC “AAL Ten increase rate of turn descend and maintain four thousand”
1 = Substitution of rate of turn	1-“decrease rate of turn”
Readback Errors Type (ALT)	ATC “AAL Ten climb and maintain one two thousand”
1 = Substitution of message numbers	1-“to one three thousand”
2 = Transposition of message numbers	2-“climb two one thousand”
3 = One type of information read back as another type	3-“one two zero knots”
4 = Not assigned	
5 = Omission of number element	5-“two thousand”
6 = Not assigned	
7 = Omission of anchor word(s)	7-“twelve”
8 = Substitution of anchor word(s)	8-“up to twelve thousand”
Readback Errors Type (ALT RSTRN)	ATC “AAL Ten maintain one thousand two hundred til DOOIN”
1 = Substitution of message numbers	1-“cross DOOIN at one thousand four hundred”
2 = Transposition of message numbers	2-“cross DOOIN at two thousand one hundred”
3 = One type of information read back as another type	3-“slow to two one zero”
4 = Omission of (point/fix)	4-“maintain one thousand two hundred”
5 = Omission of number element	6-“cross LIMA at one thousand two hundred”
6 = Transpose one (point/fix) with that of another	7-“one twenty”
7 = Omission of anchor word(s)	8-“maintain one thousand two hundred til established,”
8 = Substitution of anchor word(s)	“good rate up”
Readback Errors Type (SPD)	ATC “AAL Ten reduce speed two one zero knots til DEPOT”
1 = Substitution of message numbers	1-“two five zero knots til DEPOT”
2 = Transposition of message numbers	2-“reduce one two zero knots til DEPOT”
3 = One type of information read back as another type	3-“left two one zero”
4 = Omission of (point/fix)	4-“reduce two one zero knots”
5 = Omission of number element	5-“ten knots til DEPOT”
6 = Transpose one (point/fix) with that of another	6-“reduce one two zero knots til RIDGE”
7 = Omission of anchor word(s)	7-“two ten til DEPOT”
8 = Substitution of anchor word(s)	8-“we’ll go slow”

Table 3 (continued). Readback Error Guide Presented by Aviation Topic

Classification of Readback Errors	Examples
Readback Errors Type (APCH_DEPTR)	ATC “AAL Ten cleared ILS runway two one right approach”
1 = Substitution of message numbers	1-“cleared ILS runway two one left approach”
2 = Transposition of message numbers	2-“cleared ILS runway one two right approach”
3 = One type of information read back as another type	3-“right two one zero,” “cleared to land two one right”
4 = Substitution of one type of approach with another	4-“cleared visual approach runway two one right”
5 = Omission of number element	5-“cleared ILS approach”
6 = Transpose one (point/fix) with that of another	6-“cleared ILS at Ridge two one right approach”
7 = Omission of anchor word(s)	7-“cleared approach”
8 = Substitution of anchor word(s)	8-“cleared for the final”
Readback Errors Type (FREQ)	ATC “AAL Ten contact tower one one eight point three”
1 = Substitution of frequency digits	1-“contact tower one seven point three”
2 = Transposition of message numbers	2-“contact tower one eight one point three”
3 = One type of information read back as another type	3-“squawk one one eight three”
4 = Omission of contact location	4-“eighteen point three”
5 = Omission of number element(s)	5-“ three to tower”
6 = Substitution of one contact location with another	6-“contact center eighteen point three”
7 = Omission of anchor word(s)	7-“tower eighteen three”
8 = Substitution of anchor word(s)	8-“switching”
Readback Errors Type (RTE)	ATC “AAL Ten via Victor nine J twenty eight ATL”
1 = Substitution of message numbers	1-“via Victor five J twenty eight ATL”
2 = Transposition of message numbers	2-“via Victor nine J eighty two ATL”
3 = One type of information read back as another type	3-“speed two eighty”
4 = Omission of (point/fix)	4-“Victor nine ATL”
5 = Omission of number element	5-“Victor and J”
6 = Substitution of one (point/fix) with that of another	6-“ ATL nine J twenty eight”
7 = Omission of anchor word(s)	7”nine and twenty eight”
8 = Substitution of anchor word(s)	8-“to join the departure”
Readback Errors Type (TRNSPNDR)	ATC “AAL Ten squawk two one two four”
1 = Substitution of message numbers	1-“squawk four two one three”
2 = Transposition of message numbers	2-“squawk one two two four”
3 = One type of information read back as another type	3-“altimeter two one two four”
4 = Not assigned	
5 = Omission of number element	5-“squawk one twenty four”
6 = Not assigned	
7 = Omission of anchor word(s)	7-“twenty four”
8 = Substitution of anchor word(s)	8-
Readback Errors Type (ALTM)	ATC “AAL Ten Cleveland altimeter two nine nine two”
1 = Substitution of message numbers	1-“altimeter nine two nine zero”
2 = Transposition of message numbers	2-“altimeter nine two two nine”
3 = One type of information read back as another type	3-“squawk two nine nine two”
4 = Not assigned	
5 = Omission of number element	
6 = Not assigned	
7 = Omission of anchor word(s)	
8 = Substitution of anchor word(s)	

RESULTS

Routine ATC Communication

Presented in Table 4 are the number of transmissions, the duration of the communication samples, and the number of different aircraft for each TRACON facility and sector. A simple computation of the Approach total and Departure total values presented under the heading "Number of Aircraft" and "Duration of Communication Sample" revealed that, on average, one aircraft requested and received air traffic services every 1 min 26 s in the approach sectors and every 1 min 6 s in the departure sectors. The number of ground-to-air transmissions averaged 7.25 messages per aircraft (Number of ATC Transmissions/Number of Aircraft) for approach control and 4.7 messages per aircraft for departure control. From initial contact to the hand-off to the next controller in sequence, the entire transactional communication set involved the exchange of 13 messages, on average, between a controller and pilot (this includes all of the pilot transmissions to the controller) and an allocation of approximately 76 s of airtime (per aircraft).

Only controllers' messages that contained instruction (e.g., heading, heading modification, altitude, altitude restriction, speed, approach, departure, radio frequency, route, position, or transponder aviation topics) or advisory (traffic, altimeter portion of a weather advisory) speech acts were selected for the computation of message complexity. Of the 14, 673 controller-to-pilot transmissions 12,148 met the selection criteria — 89.8% instructions (10904 messages), 5.8% advisories (704 messages), and 4.4% contained both (540 messages).

The 2,524 excluded transmissions involved aviation topics other than traffic and the altimeter portion of weather advisories (e.g., ATIS, general acknowledgment). Also excluded were requests (e.g., traffic, general sighting, type aircraft), courtesies (e.g., greeting, apology, thanks), and non-codable (e.g., delivery, equipment, other) transmissions. Neither the speaker nor receiver addresses were encoded. For a complete listing of aviation topics by speech act category see Prinzo et al. 1995.

For approach control, Figure 1 shows that of the 10,957 communication elements transmitted to pilots, the most frequently transmitted aviation topics involved headings (22%), speeds (21%), and altitudes (16%). Rarely transmitted were altimeter, heading modification, or transponder aviation topics (each were less than 1%).

For departure control, controllers transmitted 6,665 communication elements to pilots. The aviation topics most frequently transmitted were headings (31%), altitudes (28%), and radio frequency changes (20%). The most infrequent aviation topics involved altimeter (1%), altitude restriction (1%), and heading modification (less than 1%). Departure controllers would not

Table 4. Number and Duration of Transmissions, Number of Aircraft, and Communication Duration Presented by ATC Sector and TRACON Facility

	Number of Transmissions					
Source	ATC	Flight Deck	Land-line	Total	Number of Aircraft	Duration of Communication Sample
Approach						
Atlanta	1513	1580	104	3197	219	5 hr 2 min 51 s
Chicago	1730	1843	200	3773	226	5 hr 3 min 58 s
Dallas Ft Worth	1128	1231	168	2527	247	5 hr 19 min 28 s
New York	2860	2703	222	5785	290	6 hr 47 min 55 s
S. California	1350	1494	135	2979	210	6 hr 1 min 11 s
Approach Total	8581	8851	829	18261	1184	28 hr 13 min 23 s
Departure						
Atlanta	1245	1249	281	2775	239	4 hr 49 min 42 s
Chicago	737	779	196	1712	172	3 hr 12 min 37 s
Dallas Ft Worth	1360	1374	272	3006	253	5 hr 26 min 52 s
New York	1190	1400	193	2783	311	5 hr 13 min 32 s
S. California	1560	1684	69	3313	320	5 hr 13 min 49 s
Departure Total	6092	6486	1011	13589	1295	23 hr 56 min 32 s
Grand Total	14673	15337	1840	31850	2479	52 hr 9 min 55 s

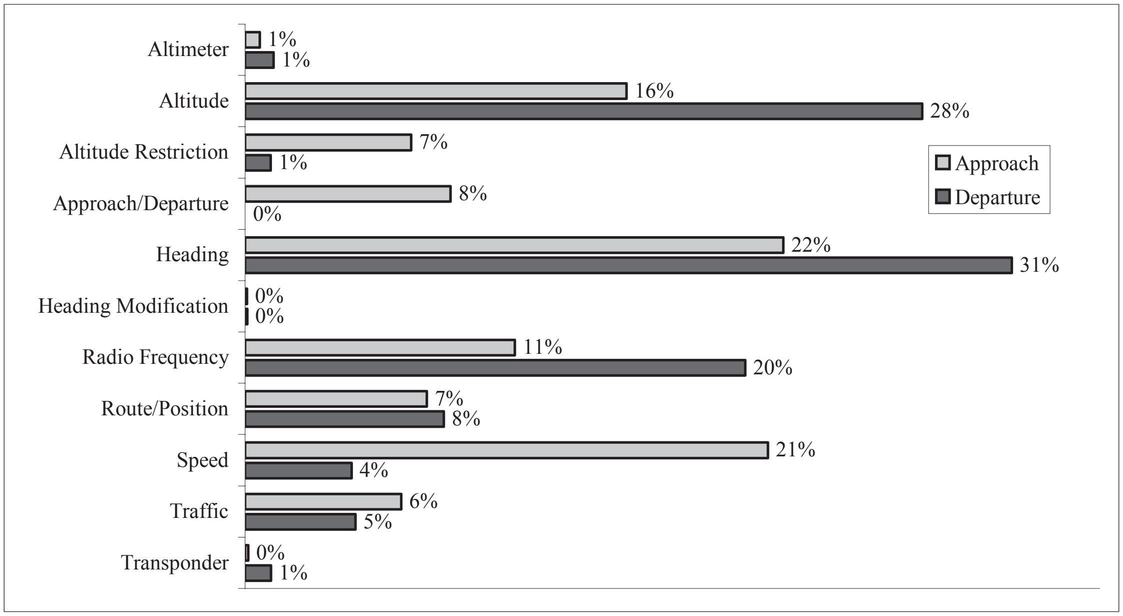

Figure 1. Percentages of ATC Aviation Topics Transmitted to Pilots

issue approach/departure clearances unless working a combined position, hence the absence of any of those aviation topics.

An examination of the frequency with which each type of aviation topic was transmitted shows interesting commonalities as well as differences. For example, regardless of the source of the transmission (i.e., ATC sector) altimeter, heading modification, and transponder information were transmitted infrequently. Approach and departure control messages involving traffic advisories and route/position were comparable in their frequency of occurrence. Departure control appeared to transmit more altitudes, headings, and radio frequencies; approach control transmitted more speeds. This finding is not surprising because there were more aircraft in the departure sample and more pilot requests for a repeat of the newly assigned radio frequency.

ATC Message Complexity

Table 5 shows the distribution of ATC messages by level of complexity. The majority of these messages (89.8%) contained instructions, 5.8% involved advisories, and 4.4% were a combination of instructions and advisories.

Unlike the findings reported by Cardosi et al. (1996) where 59% of the ATC messages involved one or two pieces of information, only 3.3% of the controller messages reported here did. Instead, when ATC messages involved only instructions, the typical complexity level varied from 4 (23.1%) to 7 (10.2%). That is, 55.7% of the controllers' messages that contained only instructions had a complexity level that ranged between 4 and 7 pieces of to-be-remembered information. There did not seem to be a pattern in the frequency of occurrence for advisories or messages that combined instructions with advisories as a function of complexity level.

Pilot Responses to ATC Messages

In response to the 12,148 ATC messages, there were 10,042 full readbacks, 967 partial readbacks, 489 acknowledgment only (e.g., 'Roger,' 'Wilco'), 149 other replies (e.g., in response to a traffic advisory, the pilot said, "SO HOW ABOUT IF WE CLIMB UP A LITTLE BIT SO WE CAN GET ABOVE HIS WAKE"), 42 courtesies such as 'Thank you,' and 457 messages with no acknowledgment.

In addition to these messages, pilots initiated 88 follow-up transmissions of which 43% were in response to traffic advisories. That is, pilots whose initial response was "Looking" updated their sighting reports with follow-up transmissions such as, "HE'S FIVE HUNDRED FEET ABOVE US RIGHT NOW." Of the remaining 57% follow-up responses, many involved uncertainty regarding previous ATC instructions. They included transmissions such as "CONFIRM THE HEADING," "VERIFY ONE THREE THOUSAND," and "SAY TOWER FREQUENCY AGAIN."

As shown in Table 6, pilots provided either full (82.7%) or partial (7.9%) readbacks to controller instructions, advisories, or both. In Cardosi et al.'s 1996 report, full readbacks occurred for 60% of the previously issued ATC messages. The data presented here indicate a 22.7%

Table 5. Percentage of Controller Messages as a Function of Level of Complexity

Level of Complexity	Types of ATC Messages: Instructions Only	Advisories Only	Instructions and Advisories	Percent of all Messages
1	00.1%			.1%
2	03.0%	.2%		3.2%
3	07.7%	.5%		8.1%
4	23.1%	.9%		24.0%
5	11.5%	.3%	.1%	12.0%
6	10.9%	.2%	.3%	11.4%
7	10.2%	.5%	.5%	11.2%
8	05.4%	.9%	.4%	6.7%
9	04.7%	.8%	.3%	5.8%
10	03.6%	.9%	.5%	5.0%
11	03.5%	.4%	.5%	4.3%
12	01.7%	.1%	.5%	2.3%
13	01.2%	.0%	.3%	.5%
14	00.7%	.1%	.3%	1.1%
15	00.6%	.0%	.3%	.9%
16	00.5%	.0%	.1%	.6%
17	00.7%	.0%	.1%	.8%
18	00.2%	.0%	.1%	.3%
19	00.2%	.0%	.1%	.3%
20 or more	00.2%	.0%	.0%	.2%
Table Total	89.8%	5.8%	4.4%	100.0%

increase in full readbacks with a corresponding decrease in partial readbacks — down from 26% in the Cardosi et al. report to 7.9%. We took the category 'Other Replies' that constituted another 7% of pilot responses in the Cardosi et al. report and split it into 'Other Replies' and 'Courtesy.' Together, they accounted for 1.6% of the pilot responses. Approximately 3.8% of the messages were not acknowledged.

These finding are particularly remarkable for lengthy controller transmissions. For example, in response to the ATC transmission, "OWNSHIP FIFTY SIX HEAVY TURN LEFT HEADING THREE ZERO ZERO YOU'RE NINE MILES FROM ANVAL MAINTAIN THREE THOUSAND FIVE HUNDRED 'TIL ANVAL CLEARED FOR THE ILS TWO SEVEN LEFT APPROACH SPEED ONE EIGHT ZERO WILL BE FINE," the pilot read back, "OWNSHIP FIFTY SIX HEAVY LEFT THREE HUNDRED CLEARED ILS TWO SEVEN LEFT THIRTY FIVE HUNDRED 'TIL ANVAL AND ONE EIGHTY SPEED." The controller's transmission had a complexity value = 20. Another example is the following pilot readback, "ONE EIGHTY TO THE MARKER TWO NINETY ON THE HEADING THIRTY FIVE HUNDRED CLEARED FOR THE APPROACH TWO FORTY EIGHT" in response to the controller's transmission, "OWNSHIP TWO FORTY EIGHT TURN LEFT HEADING TWO NINER ZERO FOUR FROM ANVAL CROSS ANVAL AT THREE THOUSAND FIVE HUNDRED CLEARED ILS RUNWAY TWO SEVEN LEFT APPROACH MAINTAIN SPEED ONE EIGHT ZERO TO THE MARKER." The controller's transmission had a complexity value = 23.

Of the 457 ATC messages that received no pilot acknowledgment, 86.0% involved messages having one (67.2%), two (16.0%), or more than two (2.8%) instructions, while another 9.4% concerned single-topic advisories for traffic (7.2%) or altimeter (2.2%) settings. The remaining 4.6% unacknowledged messages were a combination of instructions and advisories that contained

Table 6. Pilot Responses to ATC Messages

Types of Pilot Response	Types of ATC Messages			Percent of all Messages
	Instructions Only	Advisories Only	Instructions and Advisories	
Full Readback	77.1%	4.4%	1.2%	82.7%
Partial Readback	5.2%	.0%	2.7%	7.9%
Acknowledgment Only	2.8%	.9%	.3%	4.0%
Other Replies	1.1%	.1%	.0%	1.2%
Courtesy	.3%	.1%	.0%	.4%
No Acknowledgment	3.3%	.3%	.2%	3.8%
Table Total	89.8%	5.8%	4.4%	100.0%

Call Sign Usage	ACID	Example
Complete	UAL56H	UNITED FIFTY SIX HEAVY LEFT THREE SIX ZERO
Partial		
Prefix w/ some numbers/letters	DAL884	DELTA EIGHTY FOUR THREE SIXTY HEADING WE'RE SLOWING
Inc. prefix w/ all numbers/letters	ACA1017	TWO SIX TO JOIN TWENTY TWO RIGHT LOCALIZER CANADA TEN UH SEVENTEEN
No prefix w/ all numbers/letters	TRS467	NINETEEN ONE FOUR SIXTY SEVEN
No prefix w/ some numbers/letters	GWY256	FIFTY SIX LOOKING
Incorrect call sign	N21828CG	EIGHTEEN SEVENTEEN TWO CHARLIE GOLF
Unintelligible	AAL538	DOWN TO SIX AMER (UNINTELLIGIBLE)
No call sign		HEADING TWO NINER ZERO ONE SIXTY KNOTS FOLLOW THE ATR CLEARED FOR APPROACH TWO SEVEN LEFT

Figure 2. Examples of Various Types of Pilot Call Sign Usage

two (1.1%) or more than two topics (3.5%). Of the 67.2% unacknowledged single-topic instructions, 29.5% involved changes in radio frequency, 15.3% pertained to heading, 9.4% to altitude, and 6.3% to speed assignments. Transponder (3.5%), route/position (2.2%), and altitude restriction (0.9%) comprised the remainder of unacknowledged single-topic instructions.

Use of Call Sign in Readbacks. The types of call signs used by pilots and their representative examples are shown in Figure 2. In Table 7, the frequency distributions of the usage of the various types of call signs are presented by their rate of occurrence as a function of pilot responses. There were 11,806 ATC messages in this sample. A more comprehensive analysis of call sign disparities is presented later in the report.

The data presented in Table 7 indicate that pilots provided either the full (69.9%) or partial (22.1%) call sign in 92% of their responses. Call signs were excluded in 7.6% of their responses and 0.1% of the spoken call signs were unintelligible. Incorrect call signs constituted 0.3% of their responses.

There were 39 transmissions where pilots provided incorrect call signs (replacement of the assigned call sign with that of another). In 28 of these transmissions, the incorrect call signs resulted from importing numbers or letters not found in the actual call sign. For example, the pilot of Ownship 672 responded to an ATC transmission with, "OWNSHIP SIX SEVEN ZERO." In 7 other transmissions, pilots either omitted some numbers (Ownship 719 was called 'OWNSHIP SEVEN NINE'), letters ('H'

Table 7. Pilot call sign usage as a function of the type of pilot response

Pilot Call Sign Usage	Type of Pilot Response: Full Readback	Partial Readback	Ackn. Only	Other Replies	Courtesy	Follow-up	Percent
Complete	61.1%	5.8%	1.9%	.6%	.0%	.5%	69.9%
Partial							
Prefix w/ some numbers/letters	.3%	.1%	.0%	.0%	.0%	.0%	.4%
Inc. prefix w/ all numbers/letters	3.7%	.2%	.1%	.0%	.0%	.0%	4.0%
No prefix w/ all numbers/letters	13.4%	1.3%	.9%	.2%	.0%	.2%	16.0%
No prefix w/ some numbers/letters	1.4%	.1%	.2%	.0%	.0%	.0%	1.7%
Incorrect call sign	.3%	.0%	.0%	.0%	.0%	.0%	.3%
Unintelligible	.1%	.0%	.0%	.0%	.0%	.0%	.1%
No call sign	5.0%	.7%	1.0%	.5%	.3%	.1%	7.6%
Table Total	85.3%	8.2%	4.1%	1.3%	.3%	.8%	100.0%

for heavy as in 'OWNSHIP FOUR TWENTY FIVE HEAVY'), or both (Ownship1401AL was called 'ONE FOUR ONE ALPHA'). There were three transmissions where the pilot transposed some of the numbers in the call sign (e.g., N8453G was referred to as 'FIVE GULF'). Finally, in one transmission the pilot used the wrong company name with the correct flight number.

Miscommunications

Radio frequency congestion (especially during periods of heavy traffic) is a well-documented problem affecting communication efficiency (FAA 1995). Following the delivery of an ATC transmission, the controller listens for the pilot to accurately read back the original message. The presence of a mistake is called a readback error. Pilot readbacks that contain the correct information but are not phrased properly are not readback errors.

The results presented here examined the prevalence of pilot readback errors and requests for ATC to repeat all or part of a previous transmission as a function of ATC message complexity and message length (as determined by counting the number of aviation topics in the transmission) — excluding Address/Addressee and Courtesies. They were derived from 11,159 ATC transmissions. Each ATC transmission that met the selection criterion (i.e., it contained an instruction, advisory, or a combination of instruction and advisory speech acts) was paired with the pilot's response to that message. Each pilot readback was evaluated for accuracy, and the number of errors present was recorded (e.g., a zero indicated no error while a value of 3 indicated 3 errors). There were 723 individual readback errors present in 688 pilot transmissions — approximately 6% of the pilots' readbacks contained a readback error. Pearson correlations revealed that readback errors increased significantly as the complexity, $r(11159)=.196$ and message length (i.e., number of aviation topics), $r(11159)=.180$ in a controller's message increased, $p<.05$. Likewise, albeit to a lesser degree, the number of pilot requests increased significantly with message complexity, $r(11159)=.020$ and message length, $r(11159)=.054$, $p<.05$.

Message Complexity. Table 8 shows that 10,471 messages resulted in no readback errors — 93.8% of the pilots' readbacks were correct. For the 6.2% faulty pilot readbacks, 654 contained 1 error and another 34 contained 2 or more errors.[3]

ATC messages with complexity values of 10 or greater were more difficult for pilots to read back correctly, as evidenced by the presence of 2 or more errors per readback. In fact, the percentage of readback errors reached double-digit status once the threshold of 10 was crossed. Prior to reaching a complexity value of 10, the percentage of readback errors was fairly stable — ranging from as little as 2.28% (62/2718) to 6.14% (41/668). Message complexity values between 11 and 13 resulted in an increase in readback errors from 10.84% to 19.16%, while complexity values that exceeded a value of 16 had an error rate that approached 38%.

[3] Applying a liberal scoring criterion (i.e., partial readback of some numbers in a heading, speed, altitude, or radio frequency and excluding some anchor words such as fixes or points not counted) resulted in 1.3% readback errors.

Table 8. Distribution of pilot readback errors as a function of ATC message type and complexity

	Type of Message									
	Instructions			Advisories			Combination			
	Number of Readback Errors									
ATC Message Complexity	0	1	2 or more	0	1	2 or more	0	1	2 or more	Percentage of Readback Errors
1	6	0		0	0		0	0		0.00%
2	279	12		3	0		0	0		4.08%
3	773	49		34	1		0	0		5.83%
4	2583	61		70	1		3	0		2.28%
5	1260	49		26	0		14	0		3.63%
6	1158	54		24	0		27	2		4.43%
7	1074	63		49	0		43	4		5.43%
8	590	33		93	0		39	5		5.00%
9	505	39		88	0		34	2		6.14%
10	384	34	4	101	0	0	52	2	0	6.93%
11	357	47	1	38	0	0	49	6	0	10.84%
12	158	24	4	14	0	0	54	3	0	12.06%
13	103	28	3	3	0	0	29	1	0	19.16%
14	59	22	2	3	0	0	31	4	0	23.77%
15	54	20	2	2	0	0	26	2	0	22.64%
16	30	19	4	0	0	0	12	2	0	37.31%
17	54	27	3	1	0	0	12	2	0	32.32%
18	14	10	3	1	0	0	9	1	0	36.84%
19	15	9	1	2	0	0	6	2	0	34.29%
20 or more	20	13	6	2	0	0	1	1	0	50.00%
Total	9476	613	34	554	2	0	441	39	0	

Each ATC message was classified as either low (≤ 09) or high (≥10) complexity. Each pilot transmission had a readback value, and the average of those values was computed for each aircraft. An ATC Sector (Approach, Departure) by Message Complexity (Low, High) Analysis of Variance (ANOVA) was conducted on pilot readback performance. The results, evaluated using a criterion level set to $p \leq .05$, revealed that pilots produced more errors while in an approach (Mean = .126 SD = .304) compared with a departure (Mean = .038 SD = .153) sector, [F(1,3700) = 129.00]. Also, more complex ATC messages had a higher incidence of being read back incorrectly (Mean = .172 SD = .375) than messages that were less complex (Mean = .038 SD = .117), [F1,3700) = 154.39]. However, these statistically significant main effects must be qualified by the presence of a statistically significant ATC Sector by Message Complexity interaction, [F(1,3700) = 97.18] that is presented in Figure 3.

The Tukey Honestly Significant Difference (HSD) statistic revealed that pilots experienced more difficulty reading back approach control high-complexity messages than reading back departure control high-complexity messages or low-complexity messages from either approach or departure control.

Message Length. As shown in Table 9, very short messages containing only one aviation topic occurred for 54.2% of the transmissions, and they resulted in 3.84% readback errors (232/6049). Messages with 4 aviation topics appeared in 5.2% of the transmissions, producing 25.69% readback errors. Once again, pilot mean readback performance scores were computed for each aircraft call sign. The results of the ATC Sector (Approach, Departure) by Message Length (1AT, 2AT, 3AT, 4AT) ANOVA revealed that more readback errors occurred when pilots were in the approach (Mean = .113 SD = .307), as compared with the departure (Mean =

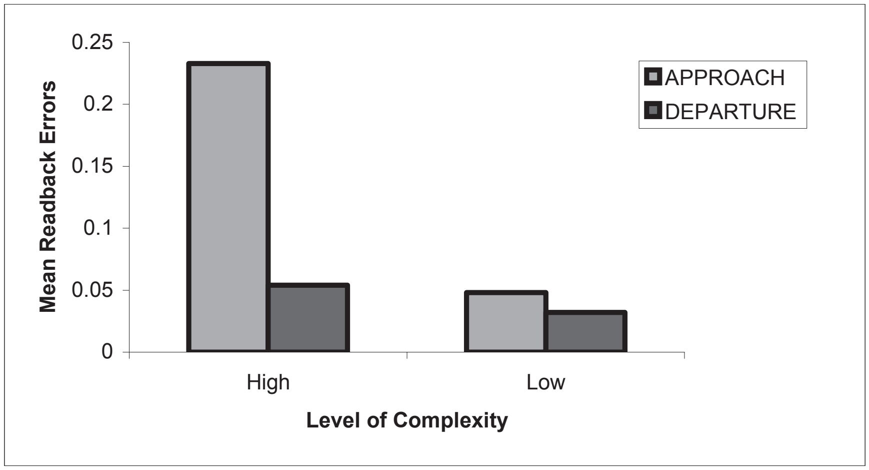

Figure 3. Mean Pilot Readback Errors Presented by ATC Sector and Message Complexity

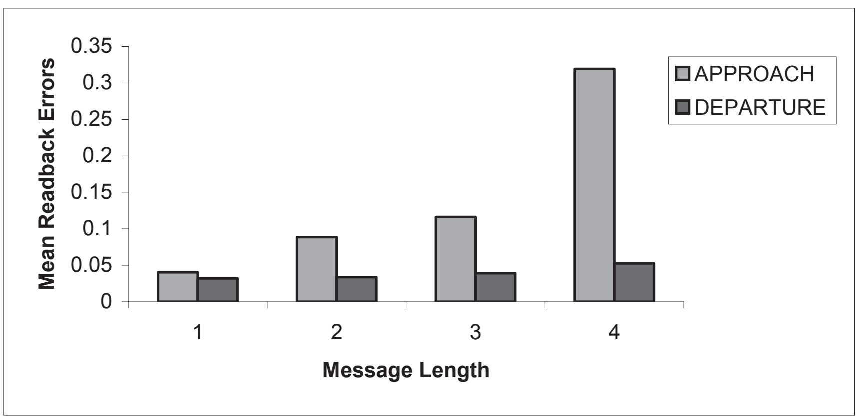

Figure 4. Mean Pilot Readback Errors Presented by ATC Sector and Message Length

Table 9. Distribution of pilot readback errors as a function of ATC message type and length

	Type of Message									
	Instructions			Advisories			Combination			
	Number of Readback Errors									
ATC Message Length	0	1	2 or more	0	1	2 or more	0	1	2 or more	Percentage of Readback Errors
1	5379	230		438	2		0	0		3.84%
2	2755	177	10	99	0		199	12		6.12%
3	996	86	4	17	0		160	19		8.50%
4	346	120	20	0	0		82	8		25.69%
Total	9476	613	34	554	2		441	39		

.0343 SD = .157) sectors, [F(1,5599) = 78.48]. As expected, the number of readback errors varied with the number of aviation topics, [F(3,5599) = 21.62]. Tukey HSD comparisons revealed that the fewest readback errors occurred when ATC messages contained one aviation topic (Mean = .036 SD = .139). There was no reliable difference between messages with 2 or 3 aviation topics (2AT = .062 SD = .214; 3AT = .082 SD = .258). However, messages with 4 aviation topics contained the most readback errors (Mean = .30 SD = .513). These main effects are qualified by a statistically significant ATC sector by message length interaction.

Figure 4 shows that as approach control messages increased from one aviation topic to between 2 and 3 topics and 4 aviation topics, that the mean number of pilot readback errors increased accordingly. The effect of message length is apparent only for approach control. There was no discernible difference between readback performance for approach and departure sectors for one aviation topic.

Readback Errors and Aviation Topic. Table 10 presents the distribution of readback errors according to the types of aviation topics read back incorrectly. Column (c) shows that 33% of the 723 identified readback errors involved speed instructions. Like the Cardosi et al. findings, there were proportionally more heading errors than radio frequency errors and proportionally fewer readback errors that involved altitude instructions. Route/position, approach/departure, altimeter, and transponder instructions captured the remaining 6.77% readback errors.

The results presented in Column (c) of Table 10, although interesting in demonstrating the overall composition of readback errors, fail to take into account the frequency of delivery of those instructions by controllers. There may be more opportunities to incorrectly read back a speed instruction simply because controllers issue them more often. Therefore, another analysis was performed that compared the number of readback errors of a particular aviation topic (e.g., speed) to the total number readbacks of that aviation topic. Column (d) shows that, when the number of readback errors is examined in conjunction with the number of actual pilot readbacks produced in Column (a), then reading back the content of an altitude restriction seems to posit greater difficultly than reading back the elements comprising a heading instruction, as well as any of the other aviation topics. In fact, there were 7.68 times more attempts at reading back headings than altitude restrictions (4176/544).

Presented in Table 11 is the distribution of type of readback errors categorized by aviation topic. Readback errors fall within three major classifications — omission (63.76%), substitution (33.61%), and transposition (2.63%). The distribution of error classes differed across aviation topic. For instance, of the 18.95% omission of anchor word(s), 12.45% involved heading (e.g., “eight zero”); almost half (11.20% of the 24.62%) of omission of number element(s) concerned speed (e.g., “eighty on the speed,” “eighty knots”); and over two-thirds of the omission of point/fix related to speed (e.g., in response to “… maintain speed one eight zero to depot,” the pilot readback “I’ll keep one eighty speed”).

Substitution of anchor word(s) and substitution of number element(s) represented nearly three-fourths of the 7 types of substitution errors. Substitution of anchor word(s) was more likely to involve altitude restrictions and speed assignments than headings or approach clearances. Similarly, substitution of number element(s) was more likely to involve radio frequency, followed by heading and

Table 10. Distribution of pilot readback errors by type of information

Type of Aviation Topic	Number of Readbacks (a)	Number of Readback Errors (b)	Proportion of Readback Errors (c)	Percentage of Readbacks in Error (d)
Altimeter	92	3	0.41 %	3.26 %
Altitude	3390	40	5.53 %	1.18 %
Altitude restriction	544	101	13.97 %	18.57 %
Approach/Departure	843	22	3.04 %	2.61 %
Heading	4176	164	22.68 %	3.93 %
Radio frequency	2115	130	17.98 %	6.15 %
Route/Position	1082	23	3.18 %	2.13 %
Speed	2264	239	33.06 %	10.56 %
Transponder	40	1	0.14 %	2.50 %
Total	14546	723	100.00%	3.26 %

Table 11. Distribution of the types of pilot readback errors according to the affected aviation topic

	Type of Aviation Topic									
Type of Readback Error	**Altm**	**Alt**	**Alt Rstr**	**App/ Dpt**	**Freq**	**Hdg**	**Rte/ Pos**	**Spd**	**Sqwk**	**Percent**
Omission of anchor word(s) n = 137			1.38%	1.24%	0.41%	12.45%	0.14%	3.32%		18.95%
Omission of contact location n = 46					6.36%					6.36%
Omission of number element(s) n = 178	0.28%	3.60%	0.14%	0.55%	4.98%	3.73%		11.20%	0.14%	24.62%
Omission of (*point/fix*) n = 100			2.35%					11.48%		13.83%
Substitution of anchor word(s) n = 50			3.04%	0.14%		0.69%	1.38%	1.66%		6.92%
Substitution of number element(s) n = 128	0.14%	1.80%	1.38%		5.81%	4.43%	1.24%	2.90%		17.70%
Substitution of one aviation topic with another type n = 56		0.14%	5.12%	0.28%	0.28%	0.97%	0.28%	0.69%		7.75%
Substitution of one contact location with another n = 1					0.14%					0.14%
Substitution of one direction with that of another (left/right) n = 3						0.41%				0.41%
Substitution of one type of approach with another type n = 3				0.41%						0.41%
Substitution of runway numbers, left/right/center n = 2				0.28%						0.28%
Transposition of number element(s) n = 1								0.14%		0.14%
Transposition of one (*point/fix*) with another n = 18			0.55%	0.14%			0.14%	1.66%		2.49%
Percent n = 723	0.41%	5.53%	13.97%	3.04%	17.98%	22.68%	3.18%	33.06%	0.14%	100.00%

speed instructions. The combination of altitude instructions with altitude restrictions accounted for about 18% of the readback errors involving substitution of number element(s).

Transposition readback errors involved reordering the number element(s) or point/fix. About 95% of the transposition errors involved reversing the order of one point/fix with another.

Hearback Errors. While a pilots' inaccurate readback of a message is called a readback error, a controllers' failure to notify a pilot of a readback error is called a *hearback error*. As noted previously, readback errors are rare events. Of the 12,148 pilot transmissions that comprised this database, 688 contained faulty read backs —about 1 in every 18 pilot transmissions. Table 12 shows that the majority of these faulty readback errors were not corrected by ATC.

ATC Corrected Readback Errors. Table 13 displays the corrected readback errors according to error classification and aviation topic. Of the corrected readbacks, 13.80 % involved omission, 79.31% involved substitution, and 6.90% involved transposition errors. It may be that some types of readback errors are more critical than others. A reexamination of the corrected readback errors was performed to compare the opportunity to correct an error with the actual number of corrections made. The findings show that only 1.74% of all the omission errors (8/61), 18.83% of the substitution errors (46/243), and 21.05% of the transposition errors (4/19) were corrected.

Pilot requests for repeat of part or all of the transmission. There are times when pilots are busy setting-up for the approach, completing checklists, or performing other station-keepings tasks, they hear, or think they hear, their aircraft's call sign on the communications system. Uncertain of the accuracy of an attempted readback, they may request a repeat of all (say again) or part (what was that heading again?) of the message. In other instances, they may request confirmation of the aviation topics that they thought they heard (confirm we're cleared down to five thousand).

An examination of the data revealed 133 messages where pilots asked controllers to repeat earlier information in either the form of a request (45.1%) or confirmation (54.9%). Of the 60 requests made, 18.3% were for a full repeat, 78.4% a partial repeat, and 3.3% asked the controller to identify the recipient of the message (who was that for?). As shown in Figure 5, radio frequency (38%) and heading (17%) assignments were more frequent partial "say agains" than altitude (5%) and route (5%) assignments.

There were 73 pilot requests for confirmation — 4.1% for a full transmission, 65.8% for a specific aviation topic, and 30.1% for the recipient of the message (was that for me?). Figure 6 shows that 23.0% of the confirmations were for headings and 16.0% were for altitude assignments.

Radio Communications Phraseology and Techniques

Presented in this section of the report are the results from the voice tapes for pilot report of altitude information, call sign discrepancies, wrong aircraft accepting a clearance, and coincident factors.

Pilot Report of Altitude Information During Initial Contact. There were 1,980 pilot reports of altitude information upon initial contact made by domestic and foreign air carrier and cargo pilots (87.5%), of which 24.8% of the pilots reported their assigned attitude only, 64.9% reported both the altitude leaving and altitude assigned, 5.0% reported only the altitude leaving, and 5.3% did not include any altitude report. Of the 282 pilot reports of altitude information made by general aviation pilots (12.5%), 51.7% reported only their assigned altitude, 29.8% included both the altitude leaving and altitude

Table 12. Percentage of hearback errors by aviation topic

Type of Aviation Topic	Number of Readback Errors	Number of Hearback Errors	Percentage of Hearback Error
Altimeter	3	3	100.00%
Altitude	40	34	85.00%
Altitude restriction	101	97	96.04%
Approach/Departure	22	18	81.82%
Heading	164	153	93.29%
Radio frequency	130	112	86.15%
Route/Position	23	18	78.26%
Speed	239	229	95.82%
Transponder	1	1	100.00%
Total	723	665	

Table 13. Distribution of the types of controller corrected readback errors according to the affected aviation topic

	Type of Aviation Topic									
Type of Corrected Readback Error (corrected/total readback errors)	**Alt**	**Alt Rstr**	**Altm**	**App/ Dpt**	**Freq**	**Hdg**	**Rte/ Pos**	**Spd**	**Sqwk**	**Percent**
Omission of anchor word(s) n = 2/137		0.00%		0.00%	0.00%	3.45%	0.00%	0.00%		3.45%
Omission of contact location n = 1/46					1.72%					1.72%
Omission of number element(s) n =4/178	1.72%	0.00%	0.00%	1.72%	0.00%	0.00%		3.45%	0.00%	6.90%
Omission of (*point/fix*) n = 1/100		0.00%						1.72%		1.72%
Substitution of anchor word(s) n = 2/50		1.72%		0.00%		1.72%	0.00%	0.00%		3.45%
Substitution of number element(s) n = 38/128	6.90%	3.45%	0.00%		29.31%	10.34%	6.90%	8.62%		65.52%
Substitution of one aviation topic with another type n = 3/56	1.72%	0.00%		1.72%	0.00%	1.72%	0.00%	0.00%		5.17%
Substitution of one contact location with another n = 0/1					0.00%					0.00%
Substitution of one direction with that of another (left/right) n = 1/3						1.72%				1.72%
Substitution of one type of approach with another type n = 0/3				0.00%						0.00%
Substitution of runway numbers, left/right/center n = 2/2				3.45%						3.45%
Transposition of number element(s) n = 1/1								1.72%		1.72%
Transposition of one (*point/fix*) with another n = 3/18		1.72%					1.72%	1.72%		5.17%
Percent n = 58/723	10.34%	6.90%	0.00%	6.90%	31.03%	18.97%	8.62%	17.24%	0.00%	100.00%

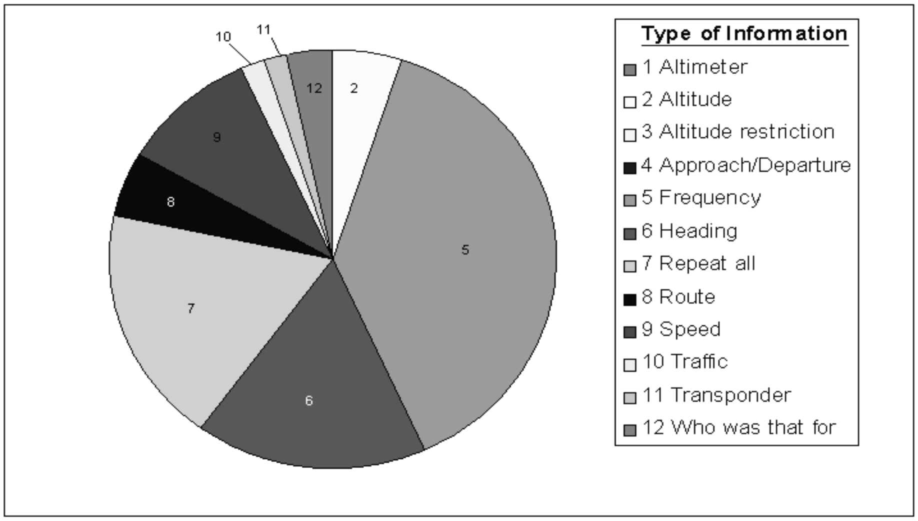

Figure 5. Requests for repetition

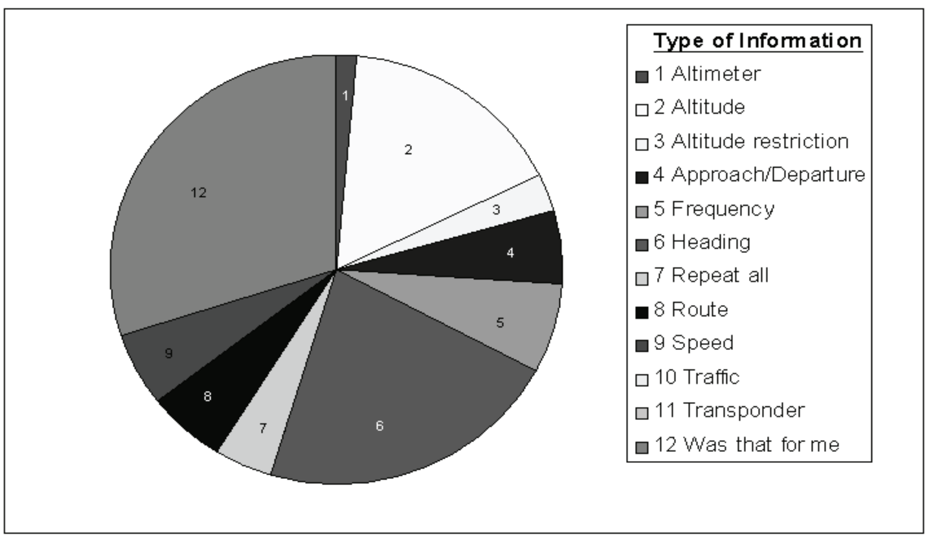

Figure 6. Requests for clarification

Table 14. Distribution of corrected and uncorrected misspoken call signs by source

Source	Misspoken Call signs Uncorrected	Corrected	Total
Domestic, Foreign and Cargo Air Carrier			
ATC	51	12	63
Flight deck	70	5	75
Total	121	17	138
General Aviation			
ATC	22	2	24
Flight deck	11	0	11
Total	33	2	35

assigned, 4.3% provided the altitude leaving and 14.2% reported no altitude information.

Pilot Responses to Altitude Clearances. Once initial contact is established, controllers instruct pilots to climb and maintain, descend and maintain, or maintain the aircraft's current altitude. There were 1,911 pilot readbacks of their first altitude assignment following radar contact and 1,320 readbacks of all subsequent transmissions with new altitude assignments. Among the domestic and foreign air carrier and cargo pilots, 93.5% reported their assigned altitude only, 5.9% reported both the altitude leaving and altitude assigned, 0.1% reported only the altitude leaving, and 0.6% did not include any altitude report. Likewise, 86.8% of the general aviation pilots reported only the assigned altitude, 10.1% included both the altitude leaving and altitude assigned, and 3.1% reported no altitude information.

Pilot readback of the remaining ATC transmissions with new altitudes followed the same pattern as initial contact and first readbacks. Once again, 93.8% of the domestic and foreign air carrier and cargo pilots reported their assigned altitude only, 5.0% reported both the altitude leaving and altitude assigned, 0.1% reported only the altitude leaving, and 1.1% did not include any altitude report. Similarly, 90.2% of the general aviation pilots reported only their assigned altitude, 6.5% included both the altitude leaving and altitude assigned, and 3.3% reported no altitude information.

Altimeter Settings. There were 143 advisories issued by controllers that included the current altimeter setting, of which 90 of the readbacks contained 2 or more digits (13.3% 2 digits, 18.9% 3 digits, 67.8% four digits). Some pilots excluded the altimeter portion (14.7%) in their readbacks when ATC messages contained both the altimeter and instructions. Acknowledgments (10.5%), courtesies (1.4%), requests for repeat or a query (2.8%), incorrect readbacks (2.1%), and no response from the pilots (7.7%) made up the remainder of the transmissions.

Call Sign Discrepancies. For this set of analyses, a detailed examination was performed of call sign usage for 28,671 of the 29,640 transmissions (969 transmissions were excluded since their contents were limited to courtesies or salutations). Unlike the analysis performed earlier that included only instructions and advisories, for this series all transmissions between pilots and controllers were examined. Of these transmissions, 76.7% contained the complete call sign, and 2.3% included an abbreviated call sign after communications were established.[4] Taking into account rounding error, call sign exclusions (6%), unintelligible call signs (.3%), incomplete call signs (14%) and other types of call signs such as substitutions (.7%) and transpositions (.1%) made up the remainder.

The distribution of misspoken call signs according to type of aircraft (e.g., air carrier, general aviation), source (ATC, flight deck), and whether or not it was corrected is presented in Table 14. Approximately 80% (138/173) of the misspoken call signs involved communication exchanges between ATC and the air carrier flight deck with the remaining 20% (35/173) attributed to communications between controllers and general aviation pilots. Approximately 88% (121/138) of the air carrier and 94% (33/35) of the general aviation misspoken call signs were uncorrected.

Presented in Table 15 is a distribution of the outcome of misspoken call signs according to the speaker of the transmission. Roughly 87% (76/87) of the controllers' disparities and 88% of the pilots' (76/86) were substitution errors followed by transpositions errors — about 13%

[4] §**4-2-4. Aircraft Call Signs.** Pilots, therefore, must be certain that aircraft identification is complete and clearly identified before taking action on an ATC clearance. ATC specialists will not abbreviate call signs of air carrier or other civil aircraft having authorized call signs. ATC specialists may initiate abbreviated call signs of other aircraft by using the *prefix and the last three digits/letters* of the aircraft identification after communications are established. The pilot may use the abbreviated call sign in subsequent contacts with the ATC specialist. When aware of similar/identical call signs, ATC specialists will take action to minimize errors by emphasizing certain numbers/letters, by repeating the entire call sign, by repeating the prefix, or by asking pilots to use a different call sign temporarily. Pilots should use the phrase "VERIFY CLEARANCE FOR (your complete call sign)" if doubt exists concerning proper identity. Also see §**2-4-20. AIRCRAFT IDENTIFICATION** for examples.

(11/87) for controllers and 7% (6/86) for pilots. About 5% (4/86) of the pilots' messages involved releasing the mic key before the end of the transmission, resulting in the omission of the final portion of the aircraft's call sign. (This was determined by visual and auditory examination of the waveform using Adobe Audition™ software).

Approximately 10% (9/87) of the controllers' misspoken call signs were detected by pilots and 6% by the controllers. Controllers either retransmitted the erroneous call sign when no readback followed their transmission (3%) or, upon self-discovery, they retransmitted the message with the correct call sign (2%).

A detailed analysis of the substitution errors revealed that for controllers, 74% (56/76) of their misspoken call signs involved replacing some numbers or letters with others (e.g., COMAIR855 replaced with COMAIR355), while another 21% (16/76) concerned exchanging one prefix for that belonging to another aircraft (e.g., AMERICAN for UNITED, DELTA for AMERICAN, JETLINK for EXECJET), and 5% (4/76) related to truncating of flight numbers (e.g., Ownship 422H was spoken as "OWNSHIP FOUR TWENTY HEAVY").

Approximately 64% (49/76) of the substitution errors made by pilots involved numbers and letters. They also rounded the ending numbers in the call sign (28%; 21/76), as well as the numbers at the beginning (5%; 4/76) (e.g., Ownship1693H spoken as "OWNSHIP SIXTEEN HEAVY"). The smallest percentage of misspoken call signs involved the substitution of ownship's prefix with that of another (3%, 2/76).

Approximately 48% of the controllers' misspoken call signs involved transmissions with one instruction that included a heading (41%), altitude (19%), speed (12%), frequency (12%), route/position (7%), transponder setting (7%), or approach/departure (2%) aviation topics. About 25.3% had 2 instructions that included a combination of altitude (25%), heading (23%), speed (20%), frequency (14%), route/position (14%), approach/departure (2%), or transponder (2%) aviation topics. Both of the transmissions that contained 3 instructions (2.3%) involved approach clearances the provided a combination of route/position, speed, or heading aviation topics. In addition to providing an approach clearance, the transmission with 4 instructions (1.1%) also included a route/position, heading, and switch in tower frequency. No instructions were included in 23% of the controllers' transmissions.

For pilots, 41% of their transmissions that contained a misspoken call sign involved the readback of one heading (37%), altitude (31%), frequency (20%), speed (9%), or transponder setting (3%). For transmissions with 2 instructions (26%), their readbacks were a composition of heading (39%), route/position (23%), altitude (18%), approach/departure (9%), speed (9%), and frequency assignment (2%). The remaining six readbacks (7%) had 3 instructions that combined aviation topics such as heading (17%), altitude (17%), speed (17%), approach/departure (17%), altitude restriction (11%), frequency (11%), route/position (6%) and transponder setting (6%). Approximately 3% of the transmissions did not include a readback to controller instructions, and 27% involved replies to transmissions that did not include instructions.

Wrong Aircraft Accepting a Clearance. As with the Cardosi et al. report that identified 7 instances of a stolen transmission, a thorough examination of the 50-plus hr of communication found four events that involved the wrong aircraft accepting a transmission meant for a different aircraft, and none of them involved anything less than the use of either the full or abbreviated call sign.

The first event involved the same airline but different flight identifiers. Both aircraft were on approach to the point where each was expecting a radio frequency assignment switching them over to the tower. The second event also involved the same airline but different flight identifiers. This time the aircraft were on departure and expecting a hand off to the next departure sector. When the radio frequency assignment was given, the wrong aircraft took the frequency. The controller could not correct the problem since the pilot had already switched to the radio frequency assignment intended for the other company aircraft. In the third event, two aircraft were establishing radar contact in rapid succession. Each aircraft was flying for a different airline, but they had the same beginning and ending numbers as part of their flight identification — Two-eighty-three and two-fifty-three. The controller issued an altitude assignment upon radar contact with Ownship two-eighty-three but Othership two-fifty-three acknowledged it. The controller detected the problem and corrected it immediately. Unlike the other three events, the fourth one did not involve call sign similarities. Ownship was instructed to contact the center controller on a prescribed radio frequency. Before the pilot could reply, the departure controller issued an instruction to Othership but Ownship provided the readback. Once again, the controller immediately detected the error and informed Ownship, thereby preventing a potential problem.

Coincident Factors to Miscommunications. In this final analysis, transmissions that contained one or more faulty readbacks were examined for the presence of factors that might be correlated with, or have contributed to, its occurrence. Coincident factors included clipped/abbreviated transmissions, nonstandard phraseology, pilot expectation, language barriers, and transmission overlap (stepped-on, blocked transmissions).

Table 15. Distribution of outcomes of misspoken call signs according to source

Source	Misspoken Call Signs		Total
	Uncorrected	Corrected	
Controller			
Transpose numbers			
Response by intended aircraft	9		9
ATC retransmits when no response	2		2
Substitution			
Response by intended aircraft	49	0	49
ATC retransmits when no response	6	3	9
Pilot wants to know the intended receiver	0	6	6
No reply	7	0	7
ATC self-corrects on next message	0	2	2
Detected by Pilot	0	3	3
Total	73	14	87
Pilot			
Transpose numbers			
Response by intended aircraft	5		5
No reply	1		1
Substitution			
Response to intended aircraft	59	1	60
No reply	1	0	1
Detected by ATC	0	4	4
Initial call-up	11	0	11
Clipped			
Response by intended aircraft	4		4
Total	81	5	86

There were 207 pilot readbacks that began with an abbreviated speech act (e.g., "THIRTY HEADING," "EIGHTY SPEED," "ONE ZERO FOUR THOUSAND") that may have resulted from poor microphone technique, poor phraseology, or differences in aircraft radio transceivers. Also, once the pilot began a readback, nonstandard phraseology was another factor associated with 91 transmissions with readback errors. There was a tendency among some pilots to truncate or otherwise abbreviate the numerical values in speed, heading, or altitude assignments. In a similar way, aircraft call signs also were truncated. For example, Ownship67H became Ownship60 and Ownship528 became Ownship520. Some pilots used the "point" designation associated with radio frequencies when reading back altitudes and speeds or substituted "decimal" for the word "point" when reading back a radio frequency. Also, several pilots flying for foreign air carriers displayed some problems in English proficiency and language production. Finally, pilot expectation (n = 16) played a coincidental role in pilot readback errors and was associated with the pilot of one aircraft reading back the contents of a message meant for the pilot of a different aircraft.

DISCUSSION

Routine ATC Communication

The ideal controller-pilot communication process would show a direct 1:1 relationship between the production of an ATC message and its parroting back by the pilot-recipient. To avoid the occasion for faulty communications, general aviation pilots sometimes jot down the contents of an ATC message on a kneeboard or scratch pad clipped onto the yoke of the aircraft. In commercial aviation, pilots often change the dials on their mode control panel as they receive changes to their aircraft's heading, altitude, or speed; radio frequencies are dialed into their second radio transceiver.

When the controller finishes the message, the pilot will read it back along with the aircraft's call sign. In return, the controller actively listens to (i.e., hearback) the recitation of the message to verify that the contents of the original transmission were properly received and understood by the intended pilot. This process is commonly referred to as the 'readback/hearback' loop.

In the unlikely case that the pilot erroneously reads back some of the contents of the original message, the controller has the opportunity to correct it by retransmitting either the entire message or only the portion that was read back incorrectly. A readback error is the incorrect recitation of an ATC transmission by the intended recipient of that transmission. Likewise, a hearback error is the failure of the originator of that transmission to correct the faulty readback.

The results presented in this report provide a description and summary of the controller-pilot communication process that occurred during normal, day-to-day operations in the terminal approach control environment. On average, across the five sampled TRACON facilities, one aircraft requested and received air traffic services every 1 min 26 s in the approach sectors and 1 min 6 s in the departure sectors. The number of ground-to-air transmissions averaged 7.25 messages per aircraft for approach control and 4.7 ground-to-air messages for departure control. Approximately 13 messages were exchanged (from initial contact until the aircraft was switched to the next controller in sequence) that involved an allocation of about 1 min 16 s of airtime per aircraft.

For approach control, typically transmitted messages involved heading, speed, and altitude instructions, while for departure control, heading, altitude, and radio frequency instructions were commonplace. Rarely did messages from approach control contain aviation topics related to the altimeter, heading modification, or transponder aviation topics. Likewise, departure controllers seldom transmitted messages containing an altimeter setting, altitude restriction or a heading modification.

Unlike the findings reported by Cardosi et al. (1996) where 59% of the ATC messages involved one or two pieces of information, we found that when controllers transmitted only instructions, almost half of their messages had a fairly low level of complexity (ranging between 4-7 pieces of to-be-remembered information). There did not seem to be a pattern in the frequency of occurrence for advisories or messages that combined instructions with advisories as a function of level of complexity.

Since the publication of Cardosi et al.'s report 10 years ago, there has been an increase in the percentage of full readbacks made by pilots — up by 22.7%. Also encouraging is the trend among pilots to provide either the full or a partial call sign in the majority of their replies. In fact, pilots who provided a full readback also included the complete call sign in 61% of their responses (Cardosi et al. reported 37%). Where Cardosi et al. reported that 24% of the full readbacks included a partial call sign, we found only 18.8% (suggesting that most pilots included all of the call sign's numbers/letters). Again, pilots seemed to be doing a better job at providing complete and accurate information in response to controller messages. The fact that call signs were excluded in 7.6% of the readbacks and 0.1% of the spoken call signs were unintelligible leaves room for improvement.

Although unacknowledged ATC messages increased by 1.8%, this finding may be partially due to random variation, sampling error, or factors independent of message length or complexity. It is unlikely that message length was a factor since more than 75% of the unacknowledged ATC transmissions had either one instruction or advisory. Since one-third of the unacknowledged single-topic instructions involved a change in radio frequency, it may be that some pilots preset the next radio frequency assignment on their radio transceivers. Radio frequency assignments are provided on standard approach and departure charts. When the controller provides the numbers, pilots verify them against their settings and may simply switch to the next frequency.

Miscommunications

As is often the case, ATC messages contain multiple communication elements. The information content present in a communication element contributes to the level of complexity of that message. The development of the concept of message complexity is a work-in-progress. For Cardosi et al. (1996), the aircraft's call sign was not included as an element since it served only to draw the pilot's attention to the incoming transmission. Their rationale was that the aircraft's call sign was like one's name — it should not increase the pilot's memory load. Unlike one's own name that doesn't change, it is not uncommon for commercial and cargo airline pilots to receive three or more different call signs in a regularly scheduled workday — depending upon the flight number assigned to a particular flight. It is unlikely that these pilots have time to learn, let alone memorize them. In fact, many pilots have developed the habit of writing their flight numbers on a post-it, tape it to the inside of their hats and then, upon entering the flight deck, sticking it onto the front panel in line with their forward field of view. Hence, we argue that a message's complexity is partially determined by the sum of the values assigned to the information content of individual communication elements. Other factors that could affect a message's complexity include message structure, information value, importance, as well as the number of communication elements requiring pilot action.

Some communication elements are ancillary – they do not affect the pilot's ability to aviate or navigate (e.g., general acknowledgments, greetings). The more important ones provide pilots with new information, confirm pilot expectations, verify existing information, or negate that information (e.g., heading, altitude, speed instructions; approach/departure clearances; traffic advisories). For example, Rantanen and Kokayeff (2002) reported no apparent correlation between the number of elements and the complexity ranking among a set of 28 ATC clearances on the ability of a sample of airline pilots to accurately copy down previously recorded clearances. For example, in one clearance neither of the two elements (complexity rank of 12 out of 28) was copied correctly while in another with eight elements (complexity rank of 26) 91.67% were correctly reproduced. They suggest that factors such as familiarity with the operating procedures within a domain (air carrier, general aviation) and geographical location (knowing the names of the navaids, fixes, etc.) affected what pilots in their study copied accurately and what was discarded.

Several studies documented the vulnerability of pilot memory and readback performance. For example, Cardosi (1999) reported that message complexity directly affects pilot memory. Several field studies have shown fewer pilot readback errors and requests for repeats when controllers' messages were short and simple (e.g., Cardosi, 1993; Morrow & Rodvold, 1993). Likewise, laboratory studies (Morrow & Prinzo, 1999; Morrow, Rodvold, McGann, & Mackintosh, 1994) found that readback errors and pilot requests were more likely to occur in response to longer ATC messages. Finally, the operational data analyzed here provide additional evidence that readback errors and pilot requests increased with increases in complexity and message length (when measured by the number of aviation topics in a controller's message). Of particular interest, but not surprising, was the finding that pilots experienced the most difficulty reading back ATC messages when flying the approach segment of their flight. Adding to their workload the reading back of a message with more than one aviation topic or a complexity value of 10 or greater rapidly increased readback errors.

Readback errors generally fell within three major groupings — omission, substitution, and transposition errors. The type of readback error produced seemed to be related to the type of information read back. For example, pilots were more likely to omit an anchor word or phrase when reading back a heading and either exclude a number or leave out the point/fix in a speed instruction. They were more likely to substitute an anchor word(s) when reading back either an altitude restriction or speed assignment than a heading or approach clearance. When instructed to either switch frequencies, change to a new heading or alter the aircraft's speed, pilots were likely to substitute numbers. Finally, a majority of the transposition errors involved reversing the order of one point/fix with that of another within the same message.

It was surprising that controllers only corrected 8% of the readback errors. Why were so few corrected? It would seem that during the hearback process, controllers might evaluate the intrinsic safety component of each readback and then decide whether or not to correct a detected error. It would follow that some communication elements may have little or no impact on safety, and if corrected, add to radio frequency congestion and task load. In such a situation, the controllers might elect not to alert the pilot to the presence of a readback error since aircraft track and position information are available on their situation displays. In fact, when given the opportunity for researchers to listen in on a frequency while observing controllers, it is common to hear a controller whisper "close enough" when some readback errors occur. Apparently, such readback errors were not sufficient to warrant another transmission. Since controllers monitor the progress of aircraft along its route of flight, they will intervene when it is necessary to maintain safety. Consequently, actively correcting a faulty readback might be a conservative process with corrections reserved for transmissions that have a direct or immediate affect on safety, aircraft performance, traffic flow, or similar factors.

It may be that some types of readback errors are more safety-critical than others — especially when situational factors are taken into account (e.g., reading back "runway four-left approach" when "four-right" was given following the instruction "turn left"). Controllers were more likely to correct transposition errors more often than either substitutions or errors of omission. By correcting the pilot as soon as possible, the controller can prevent down-stream consequences — such as potential increases in workload and frequency congestion. For example, if radio frequency number substitution errors went uncorrected, the pilot might switch to the wrong frequency. Typically, the pilot will come back on frequency and request the radio frequency again; the controller gives it, and the pilot reads it back. This adds to the controller's workload and frequency congestion.

Finally, controllers may be less likely to correct pilots' errors of omission than substitution errors since immediacy of reply and context mitigate the potential for misunderstanding created by missing digits ("one seven zero knots" read back as "seventy knots"), anchor words ("one seventy" in response to a speed instruction), or other omissions. Also, controllers' prior knowledge (i.e., knowing that aircraft slow down on approach and speed up on departure; and at certain speeds aircraft fall out of the sky), coupled with redundant visual information (observing aircraft trajectories on their situation displays), assist them as they monitor and verify pilot compliance with their instructions.

Another recurring problem involved aircraft call signs. Aircraft identification can be presented visually or aurally using alphanumeric characters and can be received either as text, using line printers or visual displays (e.g., radar displays and avionics such a cockpit display of traffic information) or aurally over the voice radio communications system. The FAA authorization, assignment, and use of aircraft identifiers can be found in *FAA Order 7110.65, The Handbook of Air Traffic Control*. Approximately half of the misspoken call signs came from controllers, half from pilots, and the majority were corrected.

When controllers produced an incorrect call sign, it often came about from the replacement of some numbers, letters, or prefixes with others not found in the call sign. It may be that similarity in the structure of numbers/letters, data block overlap, or both contributed to call sign problems for controllers (e.g., COM355 replaced COM855; AAL for UAL, DAL for AAL, EJA for BTA). When pilots detected a disparity, they either asked the controller if the message was for them using their aircraft call sign as part of the query (e.g., "THAT FOR OWNSHIP ONE TWENTY THREE MAYBE?") or they explicitly corrected the controller's error as illustrated by the following dialogue. In response to the altitude instruction, "ALASKA SEVEN NINETY EIGHT CLIMB AND MAINTAIN ONE FIVE THOUSAND" the pilot said, "SIR THAT'S AIR CANADA SEVEN NINETY EIGHT FOR ONE FIVE THOUSAND" in which case the controller followed up with, "AIR CANADA SEVEN NINETY EIGHT THANK YOU SIR CLIMB AND MAINTAIN ONE FIVE THOUSAND."

As noted previously, pilots are at their busiest during the approach phase of their flights. They must simultaneously aviate, navigate and actively monitor the radio frequency —listening for their aircraft's call sign, anticipating an approach clearance as they near the airport. Generally, problems arising from call sign discrepancies such as similar sounding call signs are well documented (Monan, 1983; Wright & Patten, 1996; Civil Aviation Authority, 2000) and although rare, have been cited by the National Transportation Safety Board (NTSB, 2003) in aircraft mishaps. After carefully reviewing the transcripts, there are several factors that may shed light on why stolen transmissions occur. For the few instances that we have identified, the factors that seemed to go together in each case shared similar characteristics between call signs (either in the name of the airline or flight numbers), prior knowledge of the frequency of misspoken call signs that might lead some pilots to think that the controller misspoke the call sign, pilot expectations during a flight segment, and pilot confidence. To illustrate, two aircraft are flying for the same company and both are on final approach. The pilots expect to be switched to the tower shortly after receiving their approach clearance. Upon hearing the company name and the tower frequency, each pilot might assume that they are the intended recipient of the transmission — especially if not listening for the flight number. One would be right and the other wrong. Had one pilot called to verify/confirm the identity of the receiver, there would not have been a problem.

Chapter 4 of the *Aeronautical Information Manual* (FAA, 2006) provides pilots with good information about basic communication techniques, communication procedures, and phraseology. The key concept is that good communication skills promote safety through a mutual understanding between the pilot and air traffic service personnel. When pilots make their first radio call to a given air traffic control facility or controller within a facility, that message is to be spoken in a defined format. The message begins with the name of the facility being called, followed by the full aircraft identification. As stated in the AIM, "If radio reception is reasonably assured, inclusion of your request, your position or altitude, and the phrase '(ATIS) Information Charlie received' in the initial contact helps decrease radio frequency congestion. Use discretion; do not overload the controller with information unneeded or superfluous[5]". Regardless of whether making initial contact or receiving a new altitude assignment, most domestic and foreign air carrier and cargo pilots and the majority of general aviation pilots included altitude information as part of their reports and readbacks. Approximately 63% of the pilots who received the current altimeter included it in their readback.

Whether unintentional or purposeful, many pilots also made number/letter substitutions. A new trend that is occurring in pilot and controller communications is the tendency to round the numbers in the call sign and aviation topics. For example, Ownship67H became Ownship60H and Ownship528 became Ownship520. Some pilots truncated or otherwise abbreviated the numerical values in speed ("TWENTY FIVE KNOTS"), heading ("ONE FOUR" for a heading of one four zero), or altitude assignments ("DOWN TO FIVE HUNDRED"). It is possible that some of the abbreviations were due to delivery technique or equipment use, while others may reflect a heightened workload. As reported by Prinzo and McClellan (2005), disruptions to efficient information transfer from blocked, stepped-on, and clipped transmissions occurred in 1.16% of the 8,000 sampled transmissions. The premature release of the mic key clipped the end of the call sign in a few of the transmissions.

Other forms of nonstandard phraseology were also associated with readback errors. It may be that some of the phraseology used (or heard) by pilots during international flights is making its way into the NAS. Some pilots used the "point" designation associated with radio frequencies when reading back altitudes (e.g., "THREE POINT FIVE" instead of "THREE THOUSAND FIVE HUNDRED") and speeds (e.g., "TWO POINT SEVEN ON THE SPEED" for "TWO HUNDRED AND SEVENTY KNOTS") or substituted "decimal" for the word "point" when reading back a radio frequency. Also, several pilots flying for foreign air carriers displayed some problems in English proficiency and language production — for example, reading back a speed instruction as "TWO ZERO HUNDRED" instead of "two hundred knots," or responding to "maintain visual from traffic" as "MAINTAIN VISUAL APPROACH."

In summary, a comparison between the voice communications analyzed by Cardosi et al. with those presented in this report revealed differences in message complexity and readback/hearback error rates. As noted in the introduction, we conducted a more detailed, and objectively driven, content analysis that reflected greater information density than Cardosi et al. It may be that Cardosi et al.'s definition of message complexity was more congruent with the approach Prinzo, Britton, and Hendrix (1995) used to count the number of aviation topics present in messages. When the data were compared, the findings show more than 50% of controllers' messages are fairly short but information-rich.

Similarly, the differences in the degree of faulty pilot readbacks and controller hearback errors may be partially due because of the approach used to evaluate the message content. We applied the *FAA Order 7110.65* whereas Cardosi et al. do not describe their evaluation criteria. A liberal criterion reveals only a minimal increase in pilot readback errors (up 0.3%) between the two reports. Both reports show that aircraft headings and radio frequency changes still are the most frequently occurring readback errors. Likewise, there is no change in how often pilots request that controllers repeat all or some portions of their transmissions. The most notable disparity between the reports is the percentage of hearback errors — Cardosi et al. reported 40% and we reported 92%. It may be that some readback errors are relatively 'harmless' for the controller and are viewed as commonplace. To correct all readback errors could put a strain on the communications system and increase the controllers' workload. However, disregarding them all could result in unsafe acts.

When examining pilot transmissions for the presence (or absence) of the aircraft call sign, the results show that when pilots provided a full readback, the complete call sign was included in 61% of their responses (Cardosi et al. reported 37%). Where Cardosi et al. reported that 24% of the full readbacks included a partial call sign, we found 18.8%, of which 13.4% excluded the prefix but included all the numbers/letters of the call sign. Likewise, pilot/controller call sign mismatch has decreased from 0.8% to 0.3%. Finally, pilots increased their production of full readbacks — up from 60% in 1996 to more than 82% in 2005. Most striking is the finding that 10 years

[5] Aeronautical Information Manual § *4-2-3. Contact Procedures*.

ago pilots provided a full readback with a complete call sign about 37% of the time. In today's air traffic control environment, the full call sign accompanies a full readback in 61% of the pilots' readbacks.

Communicating for safety is the primary objective of the phraseology developed for and provided in *FAA Order 7110.65*. With increased international travel and the gradual migration of other phraseologies into the NAS, pilots and controllers must remain vigilant in the accurate production and recitation of ATC clearances, instructions, advisories, reports, requests, and other communications.

REFERENCES

Baddeley, A.D. (1987). *Working Memory*. Oxford, England: Oxford University Press.

Baddeley, A.D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4,* 417-23.

Baddeley, A.D. and Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Volume 8, pp. 47-89). New York: Academic Press.

Baddeley, A.D., Thomson, N., and Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior, 14,* 575-589.

Civil Aviation Authority. (April 2000). *ACCESS - Aircraft Call Sign Confusion Evaluation Safety Study*. Norwich NR3 1GN: The Stationary Office. www.caa.co.uk/docs/33/CAP704.PDF. Accessed 09 September, 2005.

Cardosi, K. (1993). *An analysis of en route controller-pilot voice communications*. DOT Report no. DOT/FAA/RD-93/11. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

Cardosi, K. (1999). *Human factors for air traffic control specialists: A user's manual for your brain.* DOT Report no. DOT/FAA/AR-99/39. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

Cardosi, K., Brett, B., and Han, S. (1996). *An analysis of TRACON (Terminal Radar Approach Control) controller-pilot voice communications.* DOT Report no. DOT/FAA/AR-96/66. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration. (1995). *The Next-Generation A/G Communications System MNS-137*. http://ntl.bts.gov/lib/000/400/400/mns137.pdf. Accessed 25 March, 2005.

Federal Aviation Administration. (2004*). FAA Order 7110.65P Air Traffic Control. www.faa.gov/ATPUBS/ATC/*. Accessed 4 November, 2005.

Federal Aviation Administration. (2006). *Flight Plan 2006–2010.* www.faa.gov/about/plans_reports/media/flight_plan_2006.pdf. Accessed 4 November, 2005.

Federal Aviation Administration. (2006). Aeronautical Information Manual: Official guide to basic flight information and ATC procedures. www.faa.gov/ATpubs/AIM/. Accessed 21February 2006.

Hayes, A.F. (2005). *An SPSS procedure for computing Krippendorff's alpha* [Computer software]. Available from www.comm.ohio-state.edu/ahayes/macros.htm. Accessed 14 February, 2006.

Krippendorff, K. (1980). *Content analysis: An introduction to its methodology*. Thousand Oaks, CA: Sage Publications.

Miller, G.A. (1956). The magical number seven plus or minus two. Some limits on our capacity for processing information. *Psychological Review*, *63*, 81-97.

Monan, W.P. (1983). *Addressee errors in ATC communications: The call sign problem.* NASA Contractor Report 166462. Moffett Field, CA: NASA Ames Research Center.

Morrow, D. and Rodvold, M. (1993). *The influence of ATC message length and timing on pilot communication.* NASA Contract Report 177621. Moffett Field, CA: NASA Ames Research Center.

Morrow, D., Rodvold, M., McGann, A., and Mackintosh, M. (1994). *Collaborative strategies in air-ground communication.* Proceedings of Aerotech '94 Conference, pp.119-24, Technical Paper #942138, Los Angeles, CA: Society of Automotive Engineers.

Morrow, D. and Prinzo, O.V. (1999). *Improving pilot/ATC voice communication in general aviation.* Report no. DOT/FAA/AM-99/21. Washington, DC: Federal Aviation Administration.

Mueller, S.T., Seymour, T.L., Kieras, D.E., and Meyer, D.E. (2003). Theoretical implications of articulatory duration, phonological similarity, and phonological complexity in verbal working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 1353-80.

National Transportation Safety Board. (2003). LAX03LA172. www.ntsb.gov/ntsb/brief.asp?ev_id=20030605X00790&key=1. Accessed 09 September, 2005.

Prinzo, O.V. (1996). *An analysis of approach control/pilot voice communications.* Report no. DOT/FAA/AM-96/26. Washington, DC: Federal Aviation Administration.

Prinzo, O.V. and Britton, T.W. (1993). *ATC/pilot voice communications – A survey of the literature*. Report no. DOT/FAA/AM-03/20. Washington, DC: Federal Aviation Administration.

Prinzo, O.V., Britton, T.W., and Hendrix, A.M. (1995). *Development of a coding form for approach control/pilot voice communications*. Report no. DOT/FAA/AM-95/15. Washington, DC: Federal Aviation Administration.

Prinzo, O.V. and McClellan, M. (2005). *Terminal radar approach control: Measures of voice communications system performance*. Report no. DOT/FAA/AM-05/19. Washington, DC: Federal Aviation Administration.

Rantanen, E.S. and Kokayeff, N.K. (2002) Pilot error in copying air traffic control clearances. In *Human Factors and Ergonomics Society 46th Annual Meeting Proceedings*. Santa Monica, CA.

Schweicker, R. and Boruff, B. (1986). Short-term memory capacity: Magic number or magic spell? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 419-25.

Wasow, T. (1997). Remarks on grammatical weight. *Language Variation and Change*, *9*, 81-105.

Wright, B. and Patten, M. (1996). Call sign confusion. ASRS Direct line, 8. http://asrs.arc.nasa.gov/directline_issues/dl8_callsign.htm. Accessed 09 September, 2005.

APPENDIX A

Instruction/Clearance Complexity Guide (*Minimum-Maximum Values)

Aviation Topic	Complexity	Phraseology
Heading	4	TURN LEFT/RIGHT HEADING *(degrees)*
	4	TURN *(degrees)* DEGREES LEFT/RIGHT
	3	TURN LEFT/RIGHT *(degrees)*
	3	DEPART (*fix*) HEADING (*degrees*)
	3	FLY HEADING *(degrees)*
	2	FLY PRESENT HEADING
	2	HEADING *(degrees)*
	1	*(degrees)*
Heading Modification	2	INCREASE RATE OF TURN
	2	GOOD LEFT/RIGHT TURN
	1	TIGHT TURN
Altitude		3=*(altitude) two digits* +THOUSAND
		2=*(altitude) one digit* + THOUSAND
		3=*(altitude) two digits* + HUNDRED
		2=*(altitude) one digit* + HUNDRED
		2=(altitude) two digits
		1=(altitude) one digit
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* HUNDRED *three* *five*
	5	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *one zero*
	4	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *four*
	*4-8	CONTINUE CLIMB/DESCENT TO *(altitude)*
	*4-8	AMEND YOUR ALTITUDE DESCEND/CLIMB AND MAINTAIN *(altitude)*
	*3-7	AMEND YOUR ALTITUDE MAINTAIN *(altitude)*
	*3-8	DESCEND/CLIMB TO *(altitude)*
	*2-6	MAINTAIN *(altitude)*
	*1-2	(*altitude*, omitted "THOUSAND" "HUNDRED")
Altitude Restriction		3=*(altitude) two digits* + THOUSAND
		2=*(altitude) one digit* + THOUSAND
		3=*(altitude) two digits* + HUNDRED
		2=*(altitude) one digit* + HUNDRED
		2=(altitude) two digits
		1=(altitude) one digit
	*4-7	EXPEDITE CLIMB/DESCENT THROUGH/TO *(altitude)*
	*4-7	CROSS *(point)* AT/ABOVE/BELOW *(altitude)*
	*4-7	MAINTAIN *(altitude)* UNTIL *(point)*
	*3-7	*(altitude)* TIL ESTABLISHED/LOCALIZER/ESTABLISHED ON LOCALIZER
	*3-6	EXPEDITE THROUGH/TO *(altitude)*
	*3-6	*(point)* AT *(altitude)*--*(altitude)* TIL (*point*)--HURRY DOWN TO *(altitude)*
	2	GOOD RATE DOWN/YOUR BEST RATE
	2	EXPEDITE CLIMB/DESCENT
	2	*(Speed assignment)* "**THEN**" DESCEND/CLIMB

Aviation Topic	Complexity	Phraseology
Speed		*2=(speed)* 1=*(number)*
	6	MAINTAIN SPEED (*speed)* TIL *(point)* **<u>OR</u>** MAINTAIN (*speed)* KNOTS TIL *(point)*
	5	MAINTAIN (*speed)* KNOTS OR GREATER **<u>OR</u>** MAINTAIN SPEED *(speed)* OR GREATER
	5	AT *(point)* SPEED *(speed)* **<u>OR</u>** AT *(point) (speed)* KNOTS
	5	REDUCE/INCREASE SPEED TO *(speed)* **<u>OR</u>** REDUCE/INCREASE TO *(speed)* KNOTS
	5	SPEED *(speed)* TIL *(point)* **<u>OR</u>** *(speed)* KNOTS TIL *(point)*
	4	MAINTAIN SPEED *(speed)* **<u>OR</u>** MAINTAIN *(speed)* KNOTS
	4	DO NOT EXCEED *(speed)* KNOTS **<u>OR</u>** DO NOT EXCEED SPEED *(speed)*
	3	MAINTAIN *(speed)* **<u>OR</u>** SPEED *(speed)* **<u>OR</u>** *(speed)* KNOTS
	3	DO NOT EXCEED *(speed)* **<u>OR</u>** SLOW TO/GO BACK TO/MAINTAIN *(speed)*
	3	INCREASE/DECREASE *(number)* KNOTS
	2	MAINTAIN PRESENT/THAT/NORMAL SPEED
	2	BEST FORWARD SPEED
	1	GO FAST
Approach/ Departure	6	CLEARED ILS RWY *(name)* R/C/L APCH
	6	CLEARED VISUAL APCH RWY *(name)* R/C/L
	5	CLEARED ILS/VISUAL RWY *(name)* R/C/L
	5	CLEARED ILS/VISUAL *(name)* R/C/L APCH
	4	CLEARED ILS RIGHT/LEFT/CENTER APCH
	3	ILS RIGHT/LEFT/CENTER APCH
	3	CLEARED ILS *(name)*
	3	CLEARED RWY *(name)*
	2	CLEARED APCH
	2	CLEARED *(type)*
	2	ILS RIGHT
	2	RWY *(name)*
	2	CLEARED VISUAL/ILS
Radio Frequency	*6-7	CONTACT *(facility/function) (frequency + point)* – could be up to four digits in frequency (2 on either side of "point")
	*5-6	(*facility/function) (frequency + point)*
	*4-5	*(frequency + point)*
	*3-4	*(frequency)*
	2	CONTACT *(facility/function)*
	1	*(facility/function)*
	1	*(change point, e.g. now, there, at/over marker/when established)*
Position/ Route	5	INTERCEPT/JOIN RUNWAY *(name)* LEFT/RIGHT LOCALIZER
	*3-5	INTERCEPT/JOIN/RESUME *(airway, course, localizer, arrival/departure, etc.)*
	3	MAINTAIN VISUAL FROM THAT TRAFFIC/HIM/THEM/MD80
	3	KEEP HIM IN SIGHT
	2	MAINTAIN VISUAL SEPARATION
	2	DIRECT *(fix)*
	2	FOLLOW THAT TRAFFIC/HIM/THEM/MD80
	2	VICTOR *(airway number)*
	2	J *(route number)*
	2	INTERCEPT/JOIN LOCALIZER
	2	RESUME OWN NAVIGATION/PROCEED ON COURSE
	1	TO JOIN
Transponder	4	RESET TRANSPONDER SQUAWK (*4 digits)*
	3	SQUAWK *(4 digits)/*CODE *(4 digits)/*IDENT
	3	SQUAWK *(4 digits)/*CODE *(4 digits)* **and** IDENT
	2	SQUAWK VFR

APPENDIX B

Advisory Complexity Guide (*Minimum-Maximum Values)

Aviation Topic	Complexity	Phraseology
Traffic		1=TRAFFIC
		1=O'CLOCK
		1=one number for O'Clock, e.g. "TWELVE"
		2=two numbers for O'Clock, e.g., "TEN TO TWELVE"
		1=MILES
		1=one digit for Miles
		2=two digits for Miles
		1=ALTITUDE
		2=ALTITUDE UNKNOWN
		3=*(altitude) two digits* +THOUSAND
		2=*(altitude) one digit* + THOUSAND
		3=*(altitude) two digits* + HUNDRED
		2=*(altitude) one digit* + HUNDRED
		2=(altitude) two digits
		1=(altitude) one digit
		1=*(direction)*
		1=*(type)*
	*8-14	TRAFFIC *(number)* O'CLOCK *(number)* MILES *(direction)*-BOUND *(altitude) (type)*
	*7-9	TRAFFIC *(number)* MILES *(number)* O'CLOCK ALTITUDE UNKNOWN
	*5-9	YOU'RE FOLLOWING *(type) (number)* O'CLOCK *(number)* MILES *(altitude)*
	2	YOU'RE FOLLOWING/GOING TO FOLLOW/YOU'LL BE FOLLOWING *(type)*
	2	TRAFFIC (NO FACTOR)
Altimeter	4	*(source)* ALTIMETER *(4 digits)*
	3	ALTIMETER *(4 digits)*