Analysis of Routine Communication
In the Air Traffic Control System

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I. Introduction

A. Purpose. Radio communication between controllers and pilots is the primary means of transferring information between ground and air in the National Airspace System. Although Air Traffic Control (ATC) communication generally enables safe and efficient air travel, the growing complexity of operations places increasing demands on this system. This is reflected in the fact that the majority of aviation safety incidents involve communication factors (e.g., Billings & Cheaney, 1981). However, little is currently known about routine ATC communication. Previous studies focus on what goes wrong during communication rather than examining the system as a whole. Therefore, we don't know how often different problems occur in daily operations or why they occur. This understanding of routine pilot-controller communication should lead to methods for improving communication efficiency and operational safety.

The present project has three related goals: (i) Describe the organization of routine controller-pilot communication. This includes identifying the basic units of communication and how they are organized into discourse, how controllers and pilots use language to achieve their goals, and what topics they discuss. (ii) Identify the types and frequency of problems that interrupt routine information transfer and prompt controllers and pilots to focus on the communication itself. We analyze the costs of these problems in terms of communication efficiency, and the techniques used to resolve these problems. (iii) We also hope to identify factors associated with communication problems, such as deviations from conventional ATC procedures.

B. Approach. The proposed research continues a field study begun this year at NASA-Ames. We have already collected and transcribed samples of routine ATC communication from four major TRACONs. We draw on theories of discourse and cognitive psychology to develop a framework for coding and analyzing the communication. We examine how controllers and pilots collaborate in order to present information and establish that it is mutually understood (Clark & Schaeffer, 1987). We also examine how these processes are shaped by cognitive constraints (e.g., limited working memory capacity) and task demands (e.g., high vs. low traffic conditions). Finally, we draw on previous aviation research to generate hypotheses about communication-related problems.

This analysis of routine ATC communication should lead to a better understanding of the causes and consequences of communication problems. For example, these problems may occur more frequently when talking about specific topics (e.g., traffic), or after procedural deviations (e.g., missing readbacks). In addition, although the problems are likely to lengthen pilot-controller transactions, some techniques for resolving them may be more efficient than others.

This understanding should produce at least two benefits. First, it will suggest modifications of existing communication practices that improve communication and therefore operational efficiency. Second, a basic understanding of the current system will help in implementing fundamental changes to this system, such as switching from radio to visual data-link (Lee, 1989).

II. Background

A. Previous studies of ATC communications. Previous studies usually focus on how ATC communication breaks down and propose taxonomies of these communication-based problems, including incorrect pilot readbacks, call-sign confusions, and radio technique problems such as "stepping on" transmissions (Billings & Cheaney, 1981; Lee & Lozito, 1989; Monan, 1983). These problems are associated with procedural factors such as nonadherence to ATC conventions (e.g, missing call-signs), language factors such as ambiguous terminology, and system factors such as traffic load and frequency congestion (Lee & Lozito, 1989; Morrison & Wright, 1989).

While documenting communication problems, these studies do not provide a comprehensive picture of how pilots and controllers communicate during routine operations. They are usually based on the Aviation Safety Reporting System data-base, which contains voluntary post-incident reports that are subject to sampling and reporting biases. For example,

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Incorrect readbacks may be commonly reported because they are salient to controller and pilot. Partial readbacks may be less salient and thus reported less often even though they can contribute to safety incidents by reducing opportunities for monitoring comprehension. Thus, it is impossible to identify how often problems occur from these data. Similarly, analyses of NTSB accident reports are limited by sampling problems (Goguen, Linde, & Murphy, 1986).

Recent aviation research has examined routine aviation communication. For example, Kanki & Foushee (1989) have studied how communication patterns contribute to crew coordination. While this work focuses on crew communication, the proposed research examines communication between crew and controllers.

Despite limitations, these aviation studies suggest that pilots and controllers are most likely to have communication problems in complex environments such as TRACON operations (Lee & Lozito, 1989), and they provide an initial set of communication problems and associated factors. Thus, we examine problems that disrupt routine communication between controllers and pilots in TRACON operations.

B. Routine Controller-Pilot Communication. We view ATC communication as a kind of conversation. In most conversation, participants follow a basic "schema" in order to achieve successful communication. The schema includes initiating a transaction, presenting information, and accepting the information as mutually understood (Clark & Schaeffer, 1987). Speakers initiate a transaction by getting the attention of their addressee(s). Next, they present information about a topic by expressing relevant parts of their mental model (Johnson-Laird, 1983). In ATC communication, controllers work off of a mental model of the navigational task that contains dynamic information about aircraft and operational conditions (Murphy, et al., 1989).

Pilots interpret the controller's message in order to identify the intended actions. In doing so they update their mental model to match the controller's model. To insure accurate communication, pilots usually indicate their interpretation so that both pilot and controller accept the information as mutually understood. This step, referred to as 'grounding' (Clark & Schaeffer, 1987), or 'checking' (Ringle & Bruce, 1981), requires collaborative work (Clark & Wilkes-Gibbs, 1986). Addressees may indicate a problem with accepting information, triggering a side sequence in which the speaker tries to repair the problem so that the information is finally accepted (Clark & Schaeffer, 1987).

Controllers and pilots are likely to trade-off the amount of attention devoted to presenting and accepting information. Because safety places a premium on accuracy in ATC communication, they should explicitly accept information in order to insure accurate understanding. On the other hand, high workload pressures them to communicate quickly, so they may minimize explicit acceptance and primarily present new information. However, this strategy may lead to understanding problems that force participants to interrupt presentation in order to clarify acceptance. Thus, the most efficient strategy requires maximizing the amount of information that is accurately presented while minimizing the attention needed to accept it (Ringle & Bruce, 1982).

This general schema implies several dimensions for analyzing ATC communications, which form the basis of our coding scheme (see Section III).

1. Discourse Organization. Conversation is usually hierarchically organized, with a transaction composed of a set of turns between two or more participants who alternate speaker and addressee roles (e.g., Sachs, Schegloff & Jefferson, 1972). Turns are composed of one or more utterances, which usually correspond to a phrase or clause functioning as a speech act.

ATC communication typically involves transactions between a controller and pilot. Transaction organization should be influenced by a range of factors. An important factor is the radio medium, which allows only one speaker at a time so that the same controller continually switches between many pilots. It also depends on the goals of controllers and pilots. Controllers should take longer turns than pilots because they primarily direct while pilots acknowledge (see Section IIIB2). They may also take fewer and longer turns in order to minimize the costs of

changing turns. This strategy may be more likely with high traffic levels since controllers have more pilots to direct. Although this strategy minimizes processing demands on the controller, it may overload the pilot's working memory, leading to comprehension problems that actually increase collaborative effort. Thus, they might use a greater number of shorter turns in high traffic conditions. Turn length may also depend on the type of addressee. For example, controllers may also spend more time with unscheduled aircraft pilots, who tend to be less familiar with TRACON operations.

2. Speech acts and grounding devices. Speakers use a variety of speech acts to accomplish their communication and task goals (Searle, 1969). We are developing a set of speech acts based on previous aviation research (Goguen, et al., 1986; Kanki & Foushee, 1989), including Identifications (speaker and addressee call-signs), Commands, Reports, Acknowledgements, Questions and Requests for Information. Acknowledgements and Identifications are designed to minimize problems with initiating transactions and with accepting information. Identifications clarify who is speaking to whom, which is critical when one controller talks with many pilots. With Acknowledgments, pilots demonstrate their understanding of presented information and allow controllers to detect and repair understanding problems. Similar devices are used in other discourse requiring accurate communication (Clark & Schaeffer, 1987). Controllers and pilots may also use standard speech act sequences, reflecting schemas that accomplish specific discourse goals (Goguen, et al., 1986).

Because of different goals, controllers and pilots may use different speech acts. Controllers should issue commands that are acknowledged by pilots. Because many pilots talk to the same controller, pilots should identify themselves more than their addressee while controllers identify their addressee more than themselves.

In addition to speech acts, participants use a variety of grounding devices to present and accept information. Acknowledgments and Identifications are speech acts that are also important grounding devices. While grounding devices overlap with speech acts, they are not the same. For example, repeating information is a common device for indicating and repairing problems (Clark & Schaeffer, 1987) and different speech acts such as reports and commands can serve this function. We expect different grounding devices to be more prevalent and varied in Routine and Problem transactions.

3. Topics. Conversations are also organized around the set of topics that speakers talk about. Like other task-oriented discourse (Grosz & Sidner, 1986), ATC topics reflect task goals. A preliminary list of aviation topics from the ATC and TRACON handbooks has been expanded during coding. These topics should depend on controller and pilot goals.

4. Communication problems. Routine presentation and acceptance of information can be disrupted by problems that require participants to focus on the communication process itself. Two general kinds of problems disrupt communication. The first involves misunderstanding presented information, with the addressee prompting the speaker to repeat or expand the presentation (Understanding problem). Second, even if the information is understood, participants must agree that the information is complete, accurate, and relevant (Information problem). Only when they agree that information is understood and relevant to the task at hand should they act on the information.

a. Problem transactions. We examine how pilots and controllers present and accept information in Routine and Problem transactions. With Routine communication, participants should primarily present information, with a minimum of explicit indication of acceptance (Ringle & Bruce, 1982). Acceptance should be more prolonged in Problem transactions since participants must interrupt presentation in order to indicate and repair problems. We examine what kinds of Understanding and Information problems arise and if they are more frequent in high traffic and with unscheduled aircraft pilots, who tend to be less experienced with TRACON communication. Finally, we also examine which devices indicate (e.g., questions) and repair (e.g., repeats, explanations) these problems. Some devices may be more efficient than others.

b. Factors associated with communication problems. Aviation research identifies a range of factors associated with communication problems. They focus on inaccuracies such as incorrect pilot readbacks and on procedural deviations such as missing readbacks since these events may not only hamper communication, but lead to operational incidents (e.g., Billings & Cheaney, 1981; Golaszewski, 1989; Monan, 1983).

Inaccuracies. Inaccuracies in ATC communication include incorrect readbacks, incorrect call-signs, and call-sign confusions, where one pilot acts on a message intended for another pilot. Incorrect readbacks frequently involve headings and altitudes and occur more often after messages with multiple commands, which suggests increased probability of interference among parts of the message stored in working memory (Billings & Cheaney, 1981; Golaszewski, 1989). We are interested in how these inaccuracies are indicated and repaired.

Procedural deviations. Procedural deviations are defined as failure to follow conventional procedures (as defined by the ATC handbook). These include missing or partial readbacks, missing speaker call-signs in acknowledgements, and missing addressee call-signs on initial contact. These deviations contribute to miscommunication and incidents (Billings & Cheaney, 1981; Lee & Lozito, 1989; Monan, 1983). They may be more likely with high traffic and in Problem transactions because pilots and controllers are devoting more attention to turn taking (with high traffic) or to resolving communication problems, and thus may be distracted from following standard procedures. These procedural deviations may in turn increase the chances of further communication problems.

Other factors. We also examine a range of other factors that may be associated with communication problems. (i) Information delivery factors such as how much or how fast information is presented. Comprehension is often taxed by rapidly presented, complex messages (Waugh & Norman, 1965; Stine, Wingfield, & Poon, 1986). (ii) Language problems such as vague or ambiguous terminology (Cushing, 1987); complex syntax, which often taxes working memory and reduces comprehension (Clark & Clark, 1977); and overly abbreviated phrases, which may heighten ambiguity (Cushing, 1987). (iii) System factors such as traffic density or familiarity with TRACON operations.

III. Summary of the project

A. Approach. We obtained samples of routine TRACON communications and developed a method for analyzing the communication based on the framework in Section II.

1. Obtaining ATC communication. We obtained audio tapes of controller-pilot communications at four of the busiest TRACONs in the United States: Bay, LAX, Chicago, and Atlanta. We sampled roughly 12 hours of communication from each TRACON: 3 hours each from two Approach and two Departure sectors. When possible, half of the communication from each sector were from high traffic conditions, and half from low traffic conditions.

2. Transcribing the communication. All samples have been transcribed verbatim into a microcomputer. To insure accurate and complete transcription, we also check all transcripts against the tapes, and continually refer to the tapes during coding. Bay and Chicago communications have been completely transcribed.

3. Coding the transcribed communication. The transcribed communication is first divided into the minimal speech acts that form the basis of the coding. The coding itself has two phases. Because our sample presents an enormous coding task, we first code the entire sample on a small set of dimensions. Based on this coding, we analyze subsets of the communication in more detail.

a. Dividing the communication. The first step is to divide the communication into minimal coding units, which roughly correspond to speech acts. Because these units can range from one word (Identification) to several phrases (Traffic report), we also coded the number of syntactic units per speech act. Bay and Chicago communication has been divided.

b. First-pass coding. This phase of coding answers several questions about routine ATC communication outlined in Section IIB.

i. Discourse organization. We are focusing on transaction and turn

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organization and length. Transactions are coded for several factors that may influence turn and speech act organization, including Speaker (pilot/controller), Sector (Approach/Departure), Aircraft (Air Carrier/Unscheduled), and Traffic (High/Low). Because we had no apriori method of verifying that high traffic communication actually involved more aircraft, we assumed that high traffic communications would require a greater amount of speech per unit time. We only found such a difference for the Approach sectors of the Bay TRACON (22.8 act units per minute vs. 16.5). Therefore, high vs. low traffic comparisons are only made for Approach sectors.

        ii. Speech acts. Using a set of speech acts adapted from prior aviation research (e.g., Kanki & Foushee, 1989), each communication unit is coded for its discourse function.

        iii. Aviation topics. The topics that controllers and pilots talk about are identified. These topics may vary with speaker and operational conditions such as type of sector and traffic level.

        iv. Problem transactions. Transactions are coded as Routine or Problem (Understanding or Information), where participants interrupt routine information transfer in order to correct, expand, or otherwise deal with the communication process itself. During first-pass coding, we examine when Problem transactions are more frequent (e.g., with high traffic). Second pass coding explores how controllers and pilots present and accept information in Problem transactions.

        v. Factors associated with Problem transactions. Finally, transactions are coded for inaccuracies such as incorrect readbacks and call-signs, procedural deviations such as missing acknowledgments, and other factors that may be associated with Problem transactions.

        c. Second pass coding. We also examine Routine and Problem transactions in more detail, focusing on how controllers and pilots indicate and repair communication problems (during the second year we will expand this phase (see Section IV). For each TRACON sector, we randomly sample 5 Understanding and 5 Information problem transactions. To compare these transactions with Routine transactions, we select the preceding Routine transaction between the same pilot and controller as in the Problem transaction. We identify if speech acts are used to initiate the transaction, present new information, or accept this information, and if acceptance is routine or indicates/repairs a problem. We also identify grounding devices. For example, transactions may be initiated with identifications, information presented with commands or reports and information accepted with acknowledgments. Finally, we identify factors that may predict problems: syntactic complexity (routine, phrasal syntax vs. clauses with explicit subject and verb); disfluencies such as pausing or false starts; nonstandard terminology or abbreviations; pronouns, which may indicate deviation from conventional ATC language; and procedural deviations.

        2. Implementing the coding scheme. Coded communications are set up as data files in a microcomputer statistical package. Lines of the file correspond to temporally ordered speech acts and columns correspond to the coding dimensions. Each coded file corresponds to a file of transcribed communication with each transaction numbered to facilitate comparison of the files.

        3. Analyzing coded communication. Coded files are analyzed with descriptive statistics (e.g., frequency of procedural deviations, mean length of transactions). Nonparametric statistics are used to compare the frequency of communication problems, deviations and other events between conditions (e.g., are procedural deviations more likely in Problem transactions?).

B. Results

        All communication samples have been transcribed. Schemes for dividing transcribed communication into acts, for first-pass coding, and for second-pass coding of Problem transactions have been developed. To date, the Bay TRACON has been divided and first-pass coded. Problem transactions have been second-pass coded and partly analyzed. The Chicago sample has been divided and is currently being coded.

        1. Reliability of coding. We checked intercoder reliability (performed by Ms. Rodvold and

Dr. Morrow) on a sample of Bay communications (47 transactions with 331 acts). There was 97% agreement on the transaction/act decisions. A set of 147 acts was then coded on first-pass dimensions. The lowest agreement across the 13 dimensions was 87%. Disagreements were resolved and used to refine the coding scheme. A check on dividing the Chicago sample (63 transactions and 288 speech acts) produced 90% agreement. First-pass coding of a subset of 198 speech acts also produced high agreement, with the lowest agreement across dimensions at 96%. Reliability checks will be repeated for each TRACON.

2. First-pass coding of Bay TRACON. Although preliminary, our results provide an initial picture of routine Bay TRACON communication, and how it changes when communication problems arise.

i. Discourse organization. Our sample contained 1710 codable transactions and 10,115 speech acts. Controllers talked with air carrier or commuter pilots in 86% of the transactions and with unscheduled aircraft pilots in 14% of the transactions. Although controllers and pilots took roughly the same number of turns in Routine transaction (1.19 for controllers and 1.28 for pilots), controllers did more talking since their turns were longer (controller: 3.46 speech acts per turn; pilot: 1.95 acts per turn). Controller turns were longest when talking to unscheduled aircraft pilots (Controller to Unscheduled pilots: 3.84 speech acts per turn; Controller to Air Carrier pilots: 3.23 speech acts). Transaction and turn length did not increase with traffic for Approach sectors.

Problem transactions were longer than Routine transactions since both controllers and pilots took more turns and used more speech acts per turn in Problem transactions (Controller Information problem: 1.61 turns and 4.59 speech acts; Controller Understanding problem: 2.08 turns and 5.37 speech acts; Pilot Information problem: 1.74 turns and 3.05 speech acts; Pilot Understanding problem: 2.01 turns and 3.24 speech acts). This increased complexity in Problem transactions is examined in more detail in Section IVB3.

ii. Speech Acts. As expected, controllers and pilots tended to use different speech acts. Controllers frequently use identifications (37% of all speech acts), primarily to identify who they are talking to, commands (38%), reports to pilots (10%), and acknowledgements (6%). This pattern did not vary with type of addressee, sector, or traffic conditions. Pilots acknowledged controller commands (47%), used identifications (26%), usually to identify themselves rather than their addressee, and reported information about current conditions such as altitude or ATIS (16%).

These speech acts reflect what controllers and pilots do in routine communication: Controllers direct pilots to perform certain actions, and because they direct many pilots at once, they insure that the message is received by the correct addressee. They also provide information (about traffic, weather, type of vector) that pilots need to carry out these actions. Pilots acknowledge these commands, indicate who is speaking, and report information that enables controllers to update their mental model of the airspace.

While not surprising, these results help validate our coding scheme by recovering the organization described by the ATC handbook. This increases our confidence in using the scheme to investigate routine communication in other TRACONs and in nonroutine communication, where conventional organization is less likely to occur.

Controllers and pilots tend to use different speech acts in Routine and Problem transactions. With Information problem transactions, they are more likely than in Routine transactions to request information that should have been presented (e.g., controller asks pilot for current altitude; 18% vs. 1%: $x^2(1)=185$, $p < .001$), or to correct themselves (16% vs. < 1%: $x^2(1)=365$, $p < .001$) or correct the speaker (6% vs. 2%: $x^2(1)=53$, $p < .001$) concerning presented information (e.g., controller corrects self on heading command, or corrects pilot's ATIS report). With Understanding problems, controllers are likely to correct the pilot (e.g., incorrect readback; 9% vs. 2%: $x^2(1)=31$, $p < .001$) or to answer pilot questions about information that was misunderstood (18% vs. 1%: $x^2(1)=250$, $p < .001$) (see Section IIIB3).

iii. Topics. Identifications were coded as speaker if they identified who was speaking, and as addressee if they identified who was spoken to. Controller identifications were usually

addressee rather than speaker (30% vs. 5%, $z = 31.3$, $p < .01$), indicating that controllers identified the pilot they were speaking to more often than themselves. They also talked about headings (15%), altitudes (10%), radio frequencies (6%) and air speed (6%), again reflecting their navigational task goals.

Because acknowledgment topics were coded as "acknowledge", this was the most frequent pilot topic (47%). Unlike controllers, pilots used more speaker than addressee identifications (15% speaker vs. 10% addressee, $z = 5.49$, $p < .05$). They also talked about altitudes (10%), usually reporting altitude on initial contact.

Pilots and controllers tended to talk about different topics in Problem and Routine transactions. As in previous research (Golaszewski, 1989; Lee & Lozito, 1989), headings and altitudes were frequent topics in all transactions (Heading: 14% in Routine, 10% in Problem transactions; Altitude: 10% in Routine, 13% in Problem transactions). However, some topics were more frequent in Problem transactions, including ATIS (6% vs. 1%: $x^2(1)=41.9$, $p < .001$), traffic (6% vs. 2%: $x^2(1)=45.2$, $p < .001$), and radio frequencies (10% vs. 5%: $x^2(1)=32.1$, $p < .001$). Speech acts about the communication itself also increased (e.g., "Sorry I blocked you"; 4% vs. < 1%: $x^2(1)=47.9$, $p < .001$).

iv. Communication problems.

a. Problem transactions. Communication in our sample from the Bay TRACON was usually routine (5.2% of transactions involved Information problems and 7.4% involved Understanding problems). We already suggested that controllers and pilots tend to use different speech acts and talk about different topics in Problem transactions. The second-pass coding results will expand this picture.

b. Inaccuracies in ATC communication. We found few inaccuracies in our sample. An analysis of these events suggest why they occur.

Incorrect readbacks. There were 33 incorrect readbacks (2% of all acknowledgments), with 55% of them corrected by controllers. In agreement with previous studies (Billings & Cheaney, 1981; Monan, 1983; Golaszewski, 1989), most involved heading commands (30%), radio frequencies (30%), and altitude commands (12%).

These incorrect readbacks may be due in part to interference from other information in the controller's message. In half of the readbacks, pilots substituted a digit from another command or report in the message for one of the digits in the incorrect number (e.g., Controller: "(Call-sign) is 6 miles from Dumba. Turn left heading 310. Maintain 4000." Pilot: "310 on the heading and uh 6000"). Moreover, the percentage of readbacks increased with the number of speech acts in the controller's message (1 speech act: 15% errors; 2 acts: 21% errors; 3 or more acts: 64% errors). These results converge with experimental evidence that working memory is highly susceptible to interference (Waugh & Norman, 1965).

Controllers used a variety of devices to correct pilots, including stressing as well as repeating corrected information, and using syntactic devices such as fronting the corrected information ("220 on the heading") or explicitly contrasting the correct and incorrect information ("That's 220, not 210"). Pilots also tended to repeat and stress the information when they acknowledged the correction. In general, stressed information is understood more accurately than unstressed information (Levelt, 1989). Thus, stress appears to be an important device for resolving problems (see Section IIIB3).

Finally, our results suggest that incorrect readbacks reduce the efficiency of communication since controllers and pilots usually took an additional turn in order to correct and accept the information (of course the cost of not correcting such inaccuracies could be much greater).

Call-sign confusion. Previous research also focuses on call-sign confusion, where a pilot takes a message intended for a different pilot (e.g., Monan, 1983). We only found one instance of this problem in 12 hours of Bay TRACON communications.

Call-sign inaccuracies. Only 1% of controller and less than 1% of pilot call-signs were inaccurate, with controllers and pilots misidentifying themselves or their addressees.

<u>c. Procedural deviations</u>.

<u>Controller deviations</u>. Only 1.5% of all controller speech acts contained a procedural deviation. Most involved identifications, such as not using an addressee call-sign (1.1% of all cases where a call-sign was required in Routine transactions) or a speaker call-sign (1.6%). Notably, missing addressee call-signs were more frequent in Problem than in Routine transactions (Information problem transactions: 2.2%; Understanding problems: 6.3%; $x^2(2)=22.2$, $p < .001$).

<u>Pilot deviations</u>. Pilot deviations were more frequent than controller deviations, with 19% of all pilot speech acts involving one or more deviations. These usually involved acknowledgments. The most frequent deviation was missing speaker call-signs from acknowledgments in Routine transactions (overall: 16.8%; unscheduled aircraft pilots dropped call-signs from 31.3% of their acknowledgments). This did not vary with traffic level. Other deviations included missing (4.5%) or partial (10.1%) readbacks from Routine transactions. Finally, both readbacks and call-signs were sometimes dropped (e.g., "roger", 3.2%), and controller messages were not acknowledged at all (1.9%). Other deviations included failure to identify the controller (4.5% of transactions), or to report altitude or ATIS (< 1%), on initial contact.

Pilot as well as controller deviations tended to increase in Problem transactions. For example, missing speaker call-signs (Information problem: 29.7%; Understanding problem: 40%; $x^2(2)=55.9$, $p < .001$) and missing acknowledgments (Information problem: 6.3%; Understanding problem: 15.5%; $x^2(2)=96.9$, $p < .001$) were more frequent in Problem transactions.

Procedural deviations may increase in Problem transactions because pilots and controllers focus on resolving communication problems, which distracts attention from following standard procedures. Conversely, procedural deviations sometimes lead to Problem transactions. For example, controllers are likely to repeat commands when they are not acknowledged by the pilot.

3. Second-pass coding of Problem transactions. Based on a preliminary analysis of half of the Bay TRACON sectors, we have identified Understanding problems such as controllers correcting incorrect readbacks, controllers repeating unacknowledged messages, and pilots asking for a repeat of a misunderstood command. Information problems included controller requests for current altitudes (which the pilot had not reported on initial contact), controllers correcting their own message or a pilot's outdated ATIS report, and pilots asking for traffic updates.

We already showed that Problem transactions tend to be longer than Routine transactions. The present analysis suggests that these transactions were longer because more speech acts were devoted to accepting rather than presenting information. For example, controller Accept speech acts (i.e., speech acts devoted to accepting rather than presenting information) increased in Problem transactions (Routine: 11%; Information problem: 40%; Understanding problem: 55%). Conversely, controller Present speech acts decreased in Problem transactions (Routine: 57%; Information problem: 43%; Understanding problem: 32%). In short, controllers spent less time presenting new information and more time indicating and repairing acceptance problems in Problem transactions.

Different grounding devices were used to indicate and repair Understanding and Information problems. Understanding problems were usually indicated by repeating information, which directly or indirectly asked for verification (69% of all devices). They were also repaired by repeating the information (50%). Information problems were usually indicated by explicit questions or requests for information (83%) and repaired by answers to these questions (42%) or by speaker self-corrections (42%). We will also examine what kinds of problems take longer to indicate and repair, and which devices are most efficient.

Finally, speakers tended to be less fluent and to produce more complex utterances in Problem transactions. Problem transactions contained more speech acts with full or multiple clauses (15% vs. 6%), more disfluencies such as pauses (9% vs. 5%), and more referring expressions such as pronouns or demonstratives such as "that" (16% vs. 8%).

In summary, we have a preliminary picture of Routine and Problem transactions in the Bay

TRACON. During routine communication, controllers usually initiate transactions with identifications and then present information with commands and reports. Pilots accept this information with identifications and acknowledgments. Participants need more time to accept information in Problem transactions, and use a variety of speech acts and other grounding devices to indicate and repair acceptance problems. In doing so, they tend to be less fluent and produce more complicated utterances, perhaps because they are less able to rely on conventional ATC language when negotiating problems. This in turn may increase the chances of further communication problems. This detailed knowledge of ATC communication should lead to proposals for improving communication accuracy and efficiency.

IV. Continuation of the Research Project

This research has been continued under Subcontract # 2000-00342240 to Sterling Software, with Dr. Morrow (employed at Decision Systems) as Principal Investigator and Dr. Barbara Kanki as NASA-Ames Technical Monitor.

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