the existing parking lot by 35 percent to about 1900 spaces. Such improvements should be adequate to handle the 620 000 annual bus passengers expected by 1985, when LAX is expected to be serving 40 million annual passengers. Another alternative is to replace the existing facility with a new one on an available piece of land about 0.8 km (0.5 mile) away, perhaps combining it with terminal facilities and administrative offices. This does not appear to be cost effective at this time.

The most promising aspect of the FlyAway Bus program is its potential for accomplishing the very goals for which it was created—that is, reducing roadway congestion (especially in the central terminal area) and parking facility needs, delaying passenger capacity saturation, and providing better levels of service.

Although the current impact of the FlyAway Bus on the LAX system is relatively small, the implications of the concept are decidedly large. An expansion of the service to cover suitable population centers throughout the service area could and would have considerable impact on ground transportation activity, reducing congestion both on roadways and in parking lots and ultimately constituting a first step in changing the automobile-dependent traveling habits of the local population.

CONCLUSIONS

In calendar year 1977, LAX served more than 28 million annual passengers. This represents a growth of about 9 percent over the previous year. Average daily automobile traffic in the central terminal area grew less than 4 percent over the same time period. This substantiates the success of both the FlyAway Bus program and the expansion of the peripheral parking lots. An expanded and improved FlyAway Bus program and a faster, more convenient transportation system from the peripheral parking lots to the central terminal area should make it possible to efficiently accommodate the forecast demand of 40 million annual passengers at LAX in the mid-1980s. Beyond that point, because of the constraints of off-airport traffic, the Los Angeles Department of Airports must look to other airports—most notably Ontario and Palmdale International—to carry the load.

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Behavioral Analysis of Verbal Interaction Between Pilots and Air Traffic Controllers

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The principles of behavior theory are used as the basis for a study of the verbal interaction between air traffic controllers and airplane pilots. The danger created by the diversity of rules and regulations that govern the behavior of pilots and controllers is shown to be a primary reason for such an analysis. Basic concepts of behavior theory are discussed in relation to air traffic control operations. Graphs compiled by using tape recordings of pilot-controller conversations are used to analyze cumulative word rates and speech content. The analysis reveals problems such as a high speech rate among air traffic controllers and aberrant patterns of behavior and response among pilots. Further application of the principles of behavior theory to air traffic control operations is recommended.

Demands are continually made on people to respond to an untold variety of "signals". How they react to those signals determines how they will respond to comparable signals in the future. The lack of a consequence can alter their future reaction to comparable signals even if their first reaction was appropriate.

The formalized study of such phenomena has developed into a body of knowledge referred to as "behavior theory" (1, 2). The most important aspect of behavior theory is the three-part reinforcement contingency: In reaction to a discriminative stimulus, a response occurs, which in turn evokes a reinforcing stimulus. It is the reinforcing stimulus that can modify the nature of future responses, for it can either strengthen or weaken behavior. The absence of a reinforcing stimulus leads to a variety of responses because there is no guidance as to the desirability of any one response.

The work described here was conducted by a behavioral psychologist in consultation with a research team that included an expert in transportation safety and a transportation specialist who is also a pilot. The following information sources and data were considered:

1. The interface between the airplane pilot and the air traffic controller, including the rules and regulations each is required to follow;
2. A significant number of National Transportation Safety Board (NTSB) reports on aircraft accidents and incidents;
3. Background visits to a control tower and an approach control facility; and
4. Tapes of conversations between pilots and air traffic controllers in a number of situations, including an accident and a near accident.

The tapes do not include all conversations of the parties involved, since the pilot could well be involved in cockpit conversations and the air traffic controller in conversations with people in the control room and neither is necessarily recorded on the channel being taped. In spite of these limitations and the small samples involved, a number of useful insights have been gained by doing a content analysis of the tapes, studying the speech rates of pilot and controller, and applying the principles of behavior theory to the results.

DESCRIPTION OF OPERATIONAL ENVIRONMENT

It is useful to consider the environment in which air traffic control operations take place. This can be divided into two parts: the general background and governing procedures.

General Background

At a given airport, the specific division of responsibility for air traffic control—when there is a division—varies with the size and complexity of the airport. On a given trip, pilots are "handed off" from en-route controller to en-route controller until they approach the vicinity of a terminal airport. At the more complex airports, they first come into contact with an approach controller. Once contact has been established, they proceed under radar control and are directed by the controller to a point at which they are ready for landing and they are handed off to a final approach controller. The final approach controller continues the operation, guiding the aircraft by radar until it is lined up with the runway and is approximately 8 km (5 miles) from the airport. At that point, the final approach controller turns the pilot over to the tower for the final landing clearance. It is the responsibility of the tower to ensure that the runway is available and that no other planes are in conflict in the immediate vicinity. Once clearance is given, however, the decision on whether to land is the specific responsibility of the pilot.

This is a general description of the sequence of control operations for commercial (and other) aircraft on arrival at a major airport. At smaller airports, the number of steps may be reduced. However, airports can easily have additional control functions (e.g., a slow-traffic controller) as well as sector coordination and hand-off personnel.

On departure, once an aircraft is airborne it is switched from the tower to a departure controller. The departure controller is responsible for keeping the aircraft climbing up and out of the area in a safe, orderly manner. This task is complex, requiring many steps and interrelating personnel. It is also performed in an environment that requires monitoring and decision making by each individual.

Governing Procedures

Because each individual involved in air traffic control is required to make continual and rapid decisions, the division of control and authority among the various parties involved is a central issue.

The pilot is governed by federal regulations that vary depending on the type of aircraft used (e.g., small reciprocating engine, turbojet, glider, or helicopter), the nature of the flight (i.e., personal or commercial), and weather conditions. In addition, professional pilots, whether airline or corporate, have their own company requirements and recommended procedures to follow.

Pilots and their flying techniques are further guided by various recommended, but not mandatory, Federal Aviation Administration (FAA) procedures. These are outlined in advisory circulars, the Airmen's Information Manual, and pilot "exam-o-grams". The FAA air traffic control manual assumes that the pilot complies with these recommended procedures.

The air traffic controller, on the other hand, is governed by FAA orders and the Manual of Operation for Air Traffic Control for his or her particular job classification. Both the orders and the manual are internal FAA publications.

A chilling example of the difficulties that can arise from such a diversity of regulations, procedures, and advisories is a 1974 air crash near Dulles International Airport outside Washington, D.C. The pilot, using an FAA approach procedure, was given a clearance by the air traffic controller. The pilot began his descent to the lowest permissible altitude as shown on the approach procedure chart—and hit the side of a mountain. This error was attributed to a misunderstanding of what the term "cleared for the approach" meant. The pilot assumed that since he was cleared for the approach he could begin his descent immediately. The controller assumed that the pilot would wait until he was over the mountain before beginning his descent. The FAA subsequently published a glossary of terms for pilots and air traffic controllers in an attempt to prevent a recurrence of this type of problem.

It is such problems in communication that are the subject of this paper. How many times had a pilot previously taken the phrase "cleared for the approach" to mean that any altitude within the permissible range, down to the minimum published altitude for the approach, was allowed, and survived only because no mountain happened to be in the way? In the terminology of behavior theory, the erroneous behavior (the incorrect response) was reinforced.

PRINCIPLES OF BEHAVIOR THEORY

Certain basic principles of human behavior can be applied to a wide variety of situations without much alteration. Behavior theory (1, 2) provides an excellent set of principles for use in analyzing behavior that is significant in transportation safety. The basic concepts of behavior theory that are relevant in the field of air traffic control are (a) the reinforcement contingency, (b) primary and conditioned reinforcement, (c) positive and negative reinforcers, (d) punishment, (e) extinction and reinforcement of undesirable responses, (f) intermittent reinforcement, and (g) discriminative stimulus control. Examples of these concepts are discussed below.

The Reinforcement Contingency

The most important aspect of behavior theory is the three-part reinforcement contingency. On particular occasions, in the presence of certain discriminative stimuli, a response or behavior is evoked. The behavior has consequences, or reinforcing stimuli. This relationship can be represented symbolically in the following way:

$$S^D \ldots R \rightarrow S^r \tag{1}$$

where

S^D = discriminative stimulus,
R = response, and
S^r = reinforcing stimulus.

S^r is the event that occurs after the response. Certain types of reinforcers (or, loosely speaking, rewards) strengthen behavior so that it occurs more frequently in the future. In some cases, however, there is no reinforcing stimulus and the behavior is weakened. In such cases, the discriminative stimulus evokes a wide variety of responses.

Primary and Conditioned Reinforcement

In the formula given above, the consequence is a conditioned reinforcer. This is most often the case. A conditioned reinforcer is, by definition, one that begins as a neutral stimulus and becomes reinforcing through experience, whereas a primary reinforcer is, by definition, one that is reinforcing from birth.

Examples of primary reinforcers are food (a primary positive reinforcer) and pain (a primary negative reinforcer). Although primary reinforcers play an important role in shaping the lives of every person, they are all modified by the conditioning history of the individual and are often not as important as conditioning reinforcers such as praise, job discipline, attention, and money.

Positive and Negative Reinforcers

A positive reinforcer is an event that strengthens the response that precedes it. For instance, a pilot might request clearance to land (the discriminative stimulus) and evoke the response or behavior from the controller of the desired permission given in a clear, crisp, and well-formatted way. The positive reinforcing stimulus from the pilot would be a "thank you" or a "well done" and a landing in the required time and place.

A negative reinforcer is an event that strengthens the desire to eliminate or avoid that event. For instance, the air traffic controller might give a clarification to a pilot that the controller judges to be adequate but the pilot (perhaps because of his own inadequacies) finds difficult to understand. In this case, the controller can receive a negative reinforcing stimulus—the burden of communicating with the pilot again—that evokes the response of cutting short or discouraging such communications.

In most situations, a multiplicity of factors are at work. For instance, the controller described above may also be subject to the positive reinforcer of the pilot's recognition of the controller's fine work.

Punishment

Punishment is an aversive event contingent on the occurrence of a particular behavior. It usually reduces the probability of that behavior occurring again under similar stimulus conditions but only for a period of time.

Unlike the effect of positive or negative reinforcement, the effect of punishment is temporary: In the absence of the punishing stimulus, behavior that was suppressed by the punishment regains its normal probability of occurrence. Punishment is not as desirable a form of control as positive or negative reinforcement, which affects behavior for a longer period of time and thus alters or shapes it in more lasting ways.

Extinction and Reinforcement of Undesirable Responses

It is often incorrectly assumed by the lay person that a desired response or behavior will continue when the reinforcement contingency is no longer in force. It is a basic observation in behavior theory, however, that, when reinforcement is discontinued (extinction), the conditioned behavior gradually decreases in strength until—if the process is continued long enough—the conditioned behavior returns to the preconditioning level.

It must be recognized that behavior varies when reinforcement is discontinued. When some of these variations in behavior are followed by positive reinforcement, the probability of the occurrence of those variants of the correct behavior is increased. It is therefore a major and critically important task to build into any communication process such as the one discussed here a set of positive reinforcers so that the various parties in the communication process can continually reinforce the desired behavior in the others. Because this is a two-way conversation, each party must have positive reinforcers for the other's behavior.

Rules that do not have a reinforcement contingency built into their application would fall into disuse. The use of punishment, which occurs only after the rules have not been followed, ensures that the rule book is followed only nominally, since only total disregard of the rule book elicits clear penalties, including dismissal. Under these conditions, blatant disregard of the rules will probably be avoided. However, variations in behavior occur that require the finer control achieved through positive reinforcement of appropriate behavior as it occurs. Explicit attention must be given to having the parties involved positively reinforce each other.

Intermittent Reinforcement

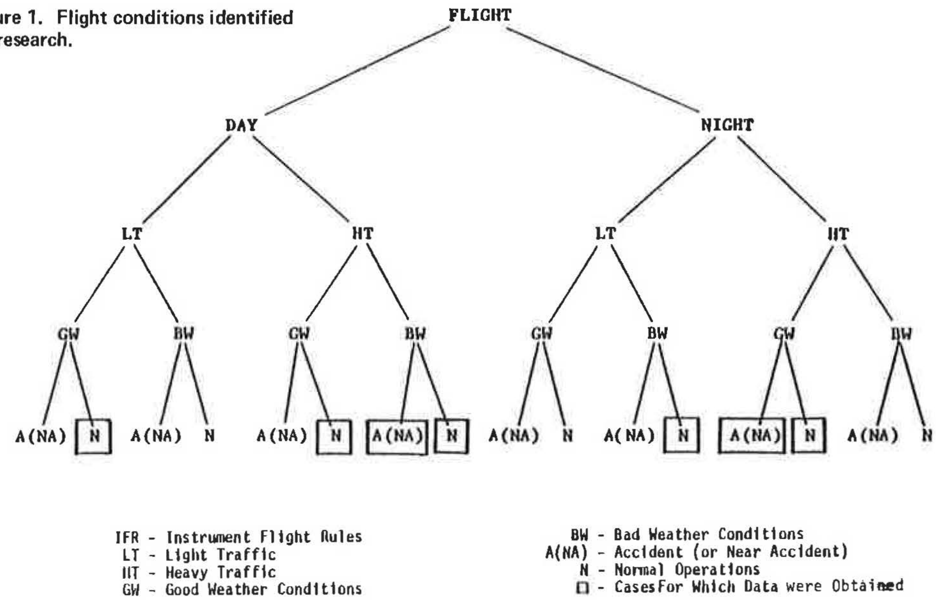
In real life, the same consequence does not always follow the same response. What happens when a response is only sometimes reinforced? Experience has revealed a somewhat startling answer: Behavior that is intermittently reinforced becomes stronger than behavior that is reinforced every time it occurs. Behavior reinforced only some of the time resists extinction to a greater extent than behavior reinforced on a continuous basis before the extinction procedure (i.e., the removal of all reinforcing stimuli) is instituted.

In the context of air traffic control operations, it is necessary to take into account not only behavior that is regularly reinforced but also—and especially—behavior that is only intermittently reinforced. From the point of view of the enforcement of regulations, it must be realized that, if undesirable behavior is permitted even some of the time, one should not be surprised if that undesirable behavior gains in strength. Indeed, according to the principle of intermittent reinforcement, it will be more difficult to extinguish such behavior than behavior that is continually reinforced. Reinforcing undesirable behavior, particularly in the face of countermanding regulations, makes those regulations lose their controlling strength in other areas as well.

Discriminative Stimulus Control

Discriminative stimuli control the behavior that is evoked only when there are appropriate consequences, or reinforcing stimuli. For example, consider that the relevant rules and regulations specify the following discriminative stimulus and behavior: The controller gives clearance instructions to the pilot (discriminative stimulus), and the pilot repeats the clearance message in the sequence given (behavior). But pilots repeat the message either in the order given or in the reverse order. Controllers provide no differential reinforcement for this; i.e., they accept the message in either order. A positive reinforcer—acknowledging the message only in its proper form—could bring the pilot's behavior under proper control. The negative reinforcer of not accepting the incorrect behavior could also con-

Figure 1. Flight conditions identified for research.



trol the behavior evoked by the discriminative stimulus. However, the discriminative stimulus (in the absence of reinforcement) does not control behavior.

DATA ACQUISITION

In pilot-controller interaction, each person's remarks constitute both the discriminative stimuli and the reinforcing stimuli for the other. In addition to the discriminative stimuli and the reinforcers provided by the participants, discriminative stimuli and reinforcers are also produced by external conditions, such as the air traffic control rules and regulations; weather, time of day, and amount of traffic; and special situations, such as another plane having trouble at the same time.

Four external factors were identified as being of primary interest in this study: (a) day versus night, (b) heavy versus light traffic, (c) good versus bad weather, and (d) "incident" versus normal operations (incident includes both accidents and near accidents). The 16 cases that illustrate these four external conditions are shown in Figure 1.

A total of eight episodes were analyzed; these represented the seven boxed cases shown in Figure 1. To obtain even the seven distinct cases, it was necessary to tape some pilot-controller conversations by using the research organization's own equipment. These tapes, unlike FAA tapes, do not have time marks. Thus, it was not possible to conduct time analyses of all of the tapes.

The duration of the pilot-controller interactions that were taped varied from 9 min to approximately 60 min and totaled about 3 h of interaction. The combinations of external conditions covered by these interactions can be summarized as follows:

1. Four day and four night interactions;
2. One accident, one near accident, and six normal-operation interactions;
3. Four heavy-traffic and four light-traffic interactions; and
4. Five bad-weather and three good-weather interactions.

For purposes of definition, good weather is considered to be a condition that allows operation by visual flight rules, and bad weather is considered to be a condition that requires operation by instrument flight rules.

Transcripts were made of all tapes. Each transcript was checked for accuracy at least once by the typist and then by the pilot and safety inspector members of the research team. Finally, the psychologist on the research team listened to portions of the tapes to further verify their accuracy.

DATA ANALYSIS AND RESULTS

Speech Rate

Analysis

One of the two formal, quantitative methods of analysis used was an analysis of pilot-controller interactions by means of graphs of the cumulative word rate. This analysis consisted of plotting the cumulative number of words as a function of time. The graphic presentation makes apparent the interrelations between the two participants as well as their speech rates.

The following rules were used to count words:

1. Speech emitted by the pilot constitutes the "pilot word rate".
2. Speech emitted by the controllers (occasionally the speech of more than one controller is on a tape) constitutes the "controller word rate".
3. The designation of an aircraft—for example, "Global 168"—is counted as one word because the complete set of symbols, words and numbers, is necessary to name the aircraft.
4. Designations of altitude, heading, speed, and the name of a destination such as "New York" are treated as single words although they are written as more than one word.

Word frequencies were calculated for periods of 5 s unless the time announcer's voice on the original tape was masked by the speech of one of the interlocutors (controller or pilot), in which case longer intervals were used. The frequencies were then cumulated over time, and the graphs were drawn. Finally, at least some examples of communication problems are written in on the graphs to point out some of the trouble spots with respect to various rates of speech by controller or pilot. Note that these illustrative communications do not include all conversations even for the accident or near-accident situation.

Results

Figure 2 shows a graph of the cumulative word rates for an interaction at night, in light traffic, in bad weather, and preceding an accident. The curves for pilot and controller speech are plotted separately as a function of time. Note that the controller has not yet heard from the plane that ultimately had the accident. The interaction recorded immediately preceded the time in which the accident occurred.

The most obvious fact is that the controller(s) speak(s) much more than the pilot. This is to be expected because the pilot is asking for, and the controller is furnishing, information. The horizontal portions of the lines indicate periods of no radio contact between controller and pilot. These periods do not necessarily mean that controllers are silent. They may be talking to other controllers or having conversations that are not recorded on the channel represented by the tape.

Figure 3 shows a graph for an interaction that occurred at night, in light traffic, and in bad weather and that included an accident. The tape illustrates a characteristic also found in the preceding case (Figure 2): The speech rate for both controllers and pilots is frequently rather high although the situation includes apparent idle time of some significant length. In general,

Figure 2. Tape of pilot-controller interaction before an accident.

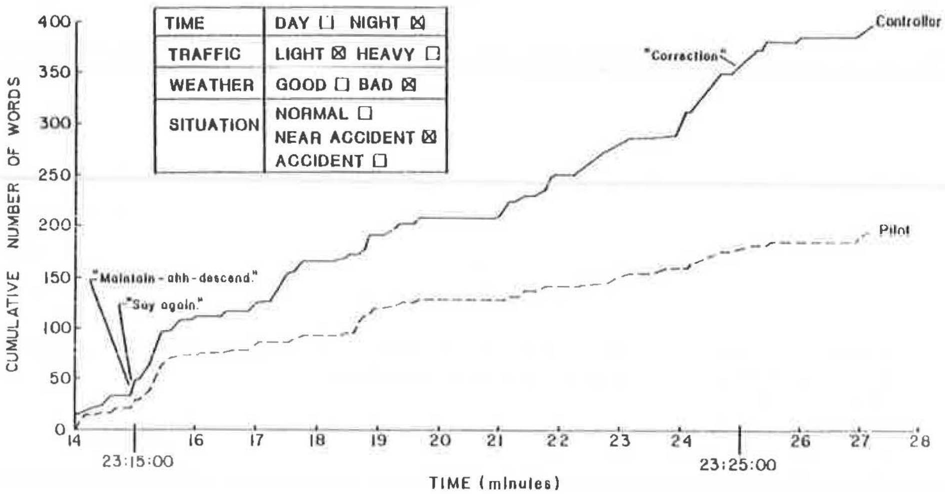
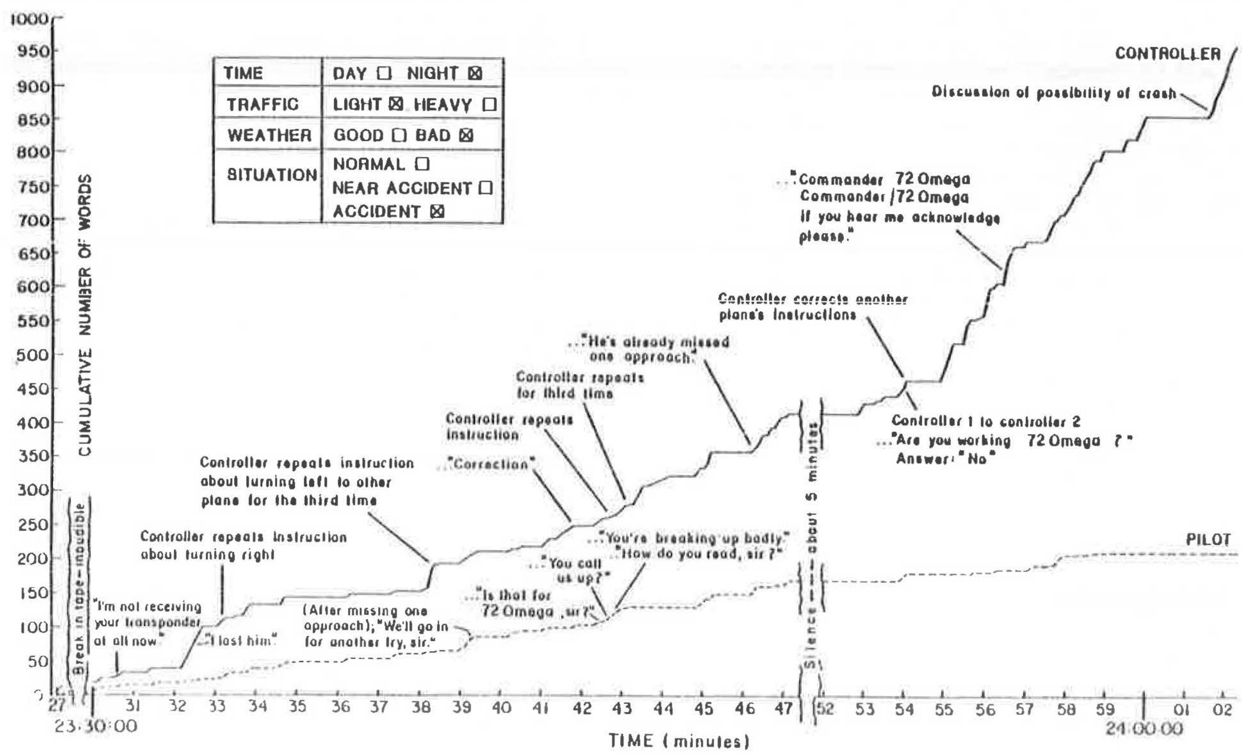


Figure 3. Tape of pilot-controller interaction including an accident.



pilots have periods in which the speech rate is slower, but the controllers tend not to have significantly slower speech rates. It is interesting to note that the traffic condition cited is light traffic, so that the controller ought not to be under pressure to go on to the next pilot, and yet the speech rate is very high. In terms of behavior theory, this nonadaptive response can be ascribed to generalization; that is, the controller generalizes from the heavy-traffic to the light-traffic condition, using a response mode that is adaptive and necessary in one condition (the high speech rate) for the other condition as well.

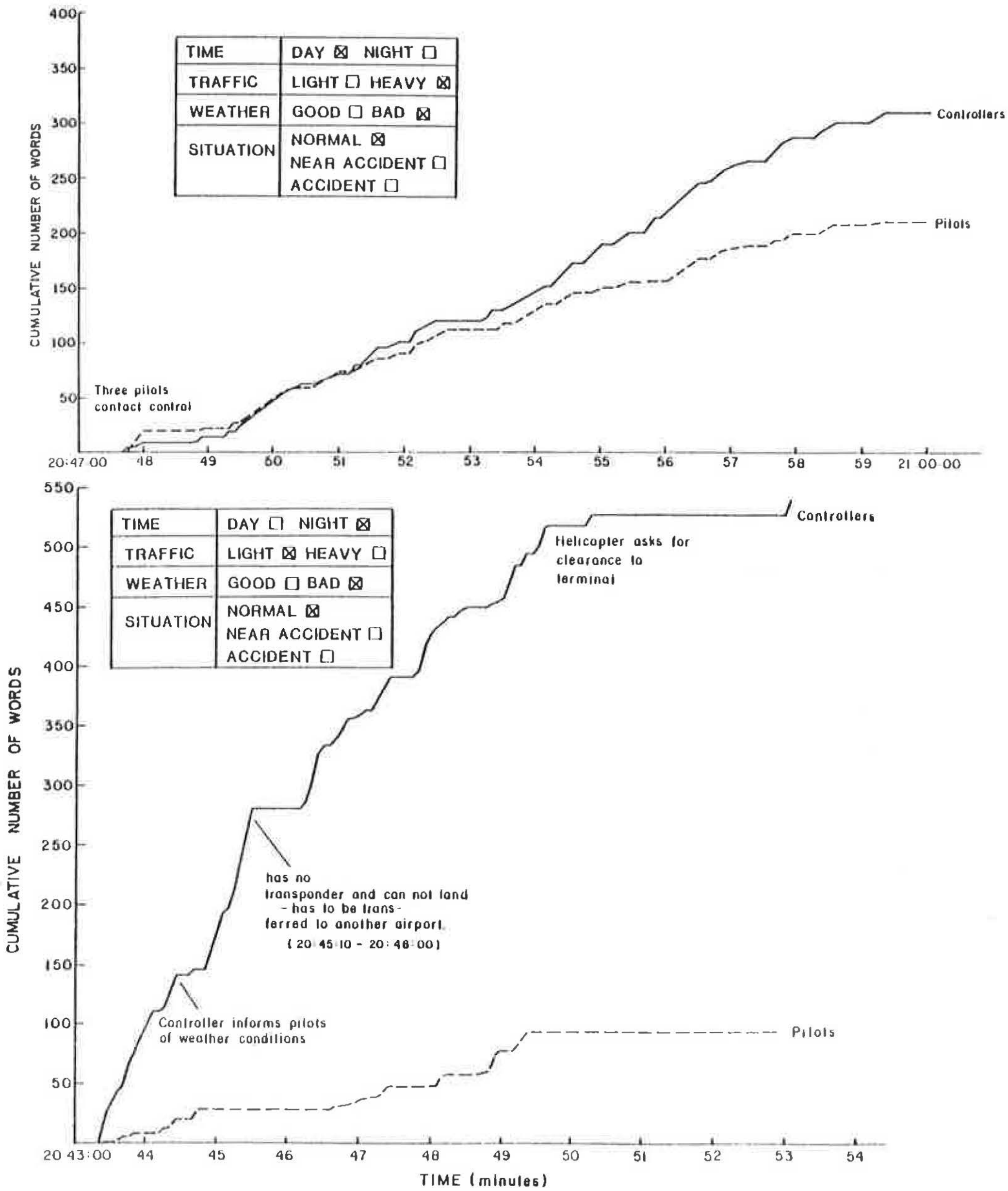
It is important to note that, although the speech rate is high, it is normally intelligible, particularly considering the limited vocabulary that is used in such communications. But a high speech rate can easily become unintelligible and can certainly put an additional burden on the participants. Cases in which this occurred were noted on other tapes; in one such case, the pilot heard incorrect information, missed the immediate correction by the controller, and became confused about what action to take.

It is testimony to the limited but critical nature of this type of communication that in many situations the controller has no direct or observational knowledge of the plane. In this particular case, the accident occurred in the gap indicated by "silence—about 5 minutes". The controller(s) continued to attempt to contact the plane well after it was lost. This is not said to imply criticism but simply to note and emphasize that the pilot and controller depend critically on the oral communication channel.

Figure 3 shows a speech rate well beyond even that found in Figure 2 as the controller(s) seek(s) information on the plane, which the weight of evidence now indicates had crashed. However, it is not this rate but the high speech rate that routinely occurs (and for which there is evidence preceding the accident) that is cited as significant.

Figure 4 shows graphs for two additional cases.

Figure 4. Rate of speech of controllers and pilots as a function of time.



More information can be extracted from these tapes with regard to specific communication problems and content, but the speed rates are generally consistent with the remarks made for the other cases.

Speech Content

Analysis

The other major category of formal, quantitative analysis is content analysis. Two major categories of speech content were used: self-correction and requests for clarifications and repetitions. Both of these categories were used to individually classify pilot speech and controller speech, which produced four categories of classification. After these frequencies were determined, each of the scores was transformed into the number of occurrences per hour in each category, for easy comparison and further analysis.

Self-Correction

Inspection of the transcripts indicated that controllers occasionally correct themselves in their communications. For example, they might say, "Maintain—ahh—descend". Sometimes the correction is preceded by the word "correction". The point of this is not to note that controllers make mistakes but rather to determine what number of such occurrences or difference in pattern from one time to another would indicate a communication problem.

Requests for Clarification and Repetition

Inspection of the transcripts showed that, in the course of information exchanges between controllers and pilots, one party occasionally did not understand or did not hear what the other party said. Examples of such requests are fairly obvious. They sometimes consist of phrases such as, "What'd ya say?" At other times, the pilot might hear only the first part of a message to which the controller appended a correction and might request clarification because the information seemed inaccurate or confusing.

Results

Figures 5 and 6 show the results of the analysis of speech content. The factors considered were good versus bad weather, light versus heavy traffic, day versus night, and normal operations versus accident or near-accident condition.

In general, the results are what one would logically expect: more corrections or clarifications in bad weather than good, at night than during the day, and before accidents than not (although for the data at hand this could be explained by other factors, since the accident and near-accident situations were both at night and in bad weather). Results for light versus heavy traffic appear anomalous: The controller produces more corrections and requires more clarifications in light than in heavy traffic.

IMPLICATIONS OF RESULTS

Word Rate

One of the most important observations extracted from the data analysis is that controllers generally speak at a high rate regardless of the traffic condition. Although there may be some justification for a high speech rate under heavy-traffic conditions, there is little justification for it in lighter-traffic conditions.

The fact that the air traffic controller is being "trained" to the higher speech rate in the heavy-traffic conditions and is transferring it (generalizing) to all conditions must be viewed with concern. In behavior theory terms, the high speech rate is apparently reinforced by the rewards of meeting the heavy-traffic situation.

Reversing Information

Some pilots respond to controller instructions by repeating the information as given, whereas others respond by repeating the information in reverse order. This introduces a degree of uncertainty under tense circumstances. Is a controller to assume that the pilot is using the reverse-order practice, or that he has perhaps misunderstood his instructions? When certain number combinations are involved, this would become critical.

The fact that this difficulty exists means that the aberrant pilot behavior is not properly reinforced and that the controller should require responses in a consistent format to avoid confusion and hazard. The controller has the opportunity—and should have the responsibility—to encourage uniform responses by questioning or challenging variants (i.e., withholding positive reinforcement for the variants and reinforcing appropriate responses).

Requests for Clarification

The speech-content analysis of the tapes included an analysis of the number of clarifications or corrections requested by pilots or given by controllers. In general, the pattern was the expected one: more clarifications and corrections in bad weather than in good, more at night than during the day, etc. One pattern, however, was the reverse of that expected: more clarifications and corrections in light traffic than in heavy traffic.

One explanation might be that the information in the light-traffic situation is "extra" or even "idle chatter"; that is, the controller has the time, or knows that the pilot has the time, to check and double-check the instructions. Another possible explanation in the same vein is that, because of the low-pressure situation, one party or the other is too casual and more prone to error.

There is, however, another, more disturbing possibility—that the controller feels that this information is needed but does not ask for it in heavy traffic because of the pressures of the situation. The controller might be responding to the more overpowering positive reinforcement of moving on to other pilots who need information and thus forego obtaining or correcting some information for each pilot. A more detailed study of this problem is certainly in order.

Number of Controllers

One possible solution to some of the problems cited here would appear to be increasing the number of controllers and thus lessening the burden on each individual controller. But it must be recognized that, under the existing air traffic control system, this would mean that each controller would be responsible for a smaller air space, and this would imply not only greater coordination problems but also a greater number of controllers and more hand-off situations per flight. An alternate solution might lie in enhanced technology that allows the controller to reduce hurried, verbal com-

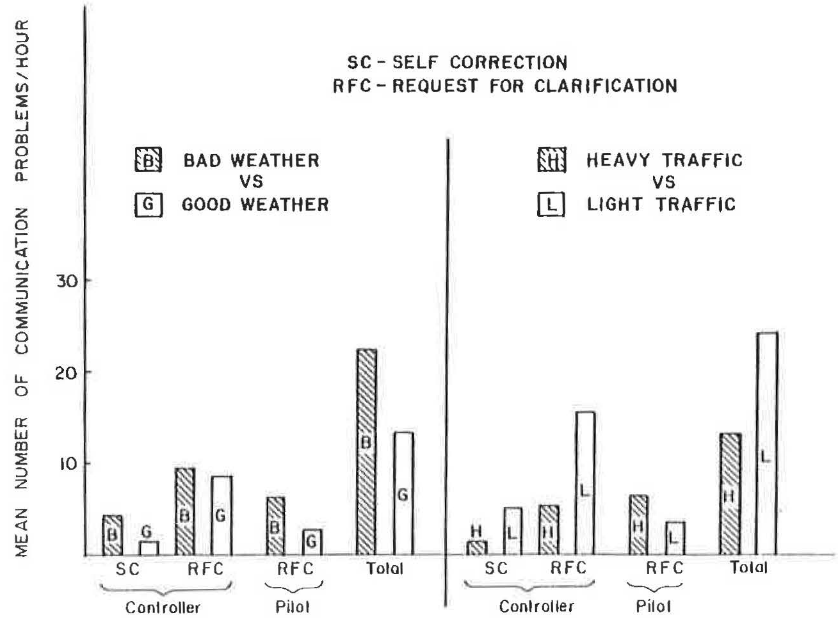


Figure 5. Analysis of speech content for good versus bad weather and heavy versus light traffic.

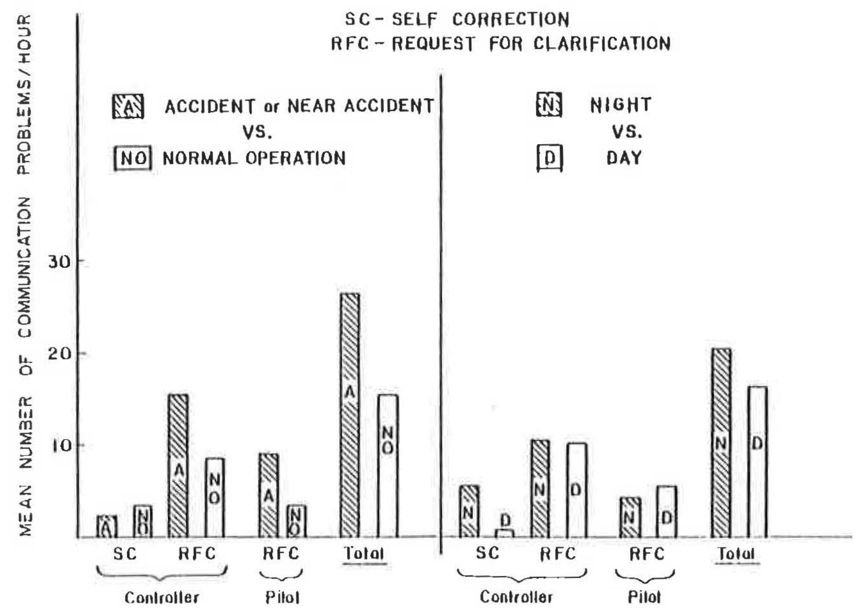


Figure 6. Analysis of speech content for accident or near-accident situation versus normal operations and night versus day.

munications and to provide unequivocal, documented instructions to each pilot.

Speech-Content Analysis

In this study, speech-content analysis has been used to good effect in documenting the difference in clarifications and corrections per unit of time under various conditions. It is recommended that such a tool be considered for use in a random-sampling monitoring procedure to discern patterns or variations that might identify potential problems. One possible flaw must be noted: Such monitoring or sampling might itself become a negative reinforcer and actually increase aberrant behavior or suppress good behavior. For instance, pilots and controllers can quickly learn that clarifications and corrections lead to a "bad score" and create artificially "good scores" by suppressing, even subconsciously, otherwise necessary clarifications and corrections.

APPLICATION OF BEHAVIORAL PRINCIPLES

A number of basic principles can be extracted from behavior theory and applied to the pilot-controller interface. Several of these principles are noted in this paper. A more extensive study might identify a number of such guiding principles and specify their applications.

As one example from the study of memory, consider the following: It is well known that saying another number after saying a number that is supposed to be remembered creates the classic condition for confusing the numbers. Yet this is precisely what happens when a pilot states an understood numeric command (such as assigned altitude) and then states the flight identification, which is itself a number.

OTHER OBSERVATIONS

Based on the limited observation of a trained observer, the following conditions or situations are worthy of note:

1. The problem of formatting the acknowledgment of a received message is troublesome because of the possible confusion of numbers and possible word clipping in transmission.
2. Similar, or possibly even identical, flight identification numbers can occur in the same air space.
3. The windowless character of some ground facilities may have subtle, adverse psychological effects on workers.

CONCLUSIONS AND RECOMMENDATIONS

Although the data base for this research was limited, the conclusions are consistent with what one would expect based on the general principles of behavior theory. A number of basic principles can be extracted from behavior theory and applied to the interface between pilots and air traffic controllers. Certainly, the opportunity to apply behavior theory to enhancing the safety of the pilot-controller interface has not been exhausted by this work. Indeed, if anything, this work has indicated the usefulness of these techniques for identifying underlying problems in such human behavior, particularly in communications. Further work along these lines is strongly recommended.

ACKNOWLEDGMENT

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Analysis of Dynamic Response of Aircraft to Profiles of Unloaded and Loaded Pavements

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A study conducted to determine whether there is a significant difference in the simulated dynamic response of an F-4C aircraft as it traverses unloaded (undeflected) or loaded (deflected) pavement is described. The U.S. Air Force computer code TAXI, which calculates vertical accelerations at three points on an aircraft as it traverses a pavement profile, was used to simulate aircraft response. An unloaded-pavement profile was obtained on a 640.5-m (2100-ft) test section. Deflections caused by a load cart equipped with an F-4C aircraft tire were measured on the same test section, and these deflections were subtracted from the unloaded-pavement profile to obtain a loaded-pavement profile. A statistical analysis was performed that consisted of two parts: (a) a test of the mean of a sample composed of the differences between acceleration responses to unloaded- and loaded-pavement profiles and (b) a test of the distribution of the acceleration responses to both types of profiles. The analyses were performed for six aircraft speeds. There was no significant difference in the responses to unloaded- and loaded-pavement profiles at speeds up to 640.5 m/s (40.7 ft/s), although at higher speeds some rejections of the mean occurred. Based on the results, it appears that the present U.S. Air Force practice of using unloaded-pavement profiles to simulate the dynamic response of aircraft is acceptable and that loaded-pavement profiles need not be obtained for this purpose.

A major problem encountered by aircraft during takeoff, landing, and taxiing operations is the high level of vertical acceleration produced by a rough runway. This response can affect the readability of on-board instruments during ground operations. This and other factors influence the overall safety of an aircraft and indicate that pavement roughness is a factor that cannot be ignored in evaluation of airfield pavements.

It has been recommended that, when the acceleration response experienced in an aircraft exceeds 0.3 *g*, remedial measures be taken (1). The Port Authority of New York and New Jersey found that the maximum level of aircraft vibration before passenger discomfort was noted was 0.12 *g* in the normal operation area and 0.3 *g* in infrequently trafficked areas (2). Hall and Kopelson (3) also used a roughness criterion based on accelerations and indicated that a runway was undesirable when the acceleration at either the pilot's station or the aircraft's center of gravity exceeded 0.5 *g*.

To control the adverse effects of a rough runway, the areas in question must be located and corrected. A subjective qualitative assessment of pavement roughness can be obtained from flight crews, but the specific area of the runway that needs repairs cannot be located in this way.

One way to effectively locate rough areas of runway pavement is to equip an aircraft with low-frequency servo accelerometers, which record the accelerations encountered while the aircraft traverses the runway. This method, however, is costly, both in time and personnel. Furthermore, since different aircraft respond to identi-