EARS FOR AUTOMATED INSTRUCTION SYSTEMS: WHY TRY?

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INTRODUCTION

Background

A principal concern of the Naval Training Equipment Center's Human Factors Laboratory is the identification and capture of those quantifiable aspects of human behavior that relate to the improvement of performance through training. This viewpoint requires, on the one hand, a constant search for new ways of looking at what people do and, on the other, a continual scan of modern technologies to spot developments that can bring abstract concepts or classifications to tangible reality.

As a result of one of these abstracting exercises, it was noted that there exists a class of job situations which have in common the use of restricted, stylized speech by people carrying out a control and/or advisory function. In the U. S. Navy, these circumstances prevail for Ground Controlled Approach (GCA) and Ground Controlled Intercept (GCI) Controllers, for several Naval Flight Officer positions such as the Radar Intercept Officer, for Landing Signal Officers and others.

Figure 1 shows an existing system used for training student controllers in the Precision Approach Radar (PAR) phase of a Ground Controlled Approach (GCA). The display of the simulated GCA control console presents to the student an azimuth, elevation and range picture of the aircraft under guidance. Through communication equipment, he transmits advisories to a "pseudo-pilot" who "flies" the simulated aircraft. Aircraft position changes which occur as a result of the pseudo-pilot's flight response are shown on the student's radar display through a video simulator. The instructor supervises training sessions, subjectively evaluates student performance and implements the overall training plan by manually selecting conditions so as to present a variety of PAR problems to the student.

Previous studies have demonstrated that in analogous situations it has been possible to achieve savings of manpower and training time while gaining a uniform, high quality student output by introducing automated adaptive instruction. This advanced technology, if applied to GCA controller training, would bring in its standard benefits such as objective performance measurement and complete individualized instruction. Moreover, for GCA controller students, a more fully automated system could provide greater realism in the performance of "aircraft" under control by accessing directly the computer model of aircraft dynamics rather than through the undetermined skills of a variety of pseudo-pilots. Additionally, the rapid processing of an automated system would make possible extrinsic feedback on his performance to the student in real time.

Now, in order to realize an automated adaptive training system, it is essential that, in addition to values of overall system performance, some relevant aspect of the student's activity, in this case his vocal output, be accessible to the performance measurement subsystem. At this point, our technology review suggested that the state-of-the-art in machine understanding of speech could furnish the means for direct entry of a student's advisories. For some whose acquaintance with this possibility is limited to the science fiction of film, television and print media, the response might be "Of course! Why not?" Those more familiar with the problem might say, "Not yet!" The reality is that, while computer understanding of continuous, unrestricted speech, without pre-training, by any individual who approaches, is still a long way off, there exists today a capability for machine recognition of isolated utterances drawn from a small set of possible phrases when the computer has been pre-trained on the language set with samples for the individual speaker. Systems that exhibit an acceptable minimum level of accuracy and reliability under these restrictions are available right now from at least one commercial vendor for less than $20,000.

Happily, the mini-languages mandated for the controller-type jobs that concern us for the most part do not exceed the limitations existing today for speech understanding. Therefore, with support from the Defense Advanced Research Projects Agency and from the Naval Air Systems Command, the Human Factors Laboratory has undertaken a program of exploratory research and development to determine the conceptual, technical and operational feasibility of advanced training systems for controller personnel. These systems would be

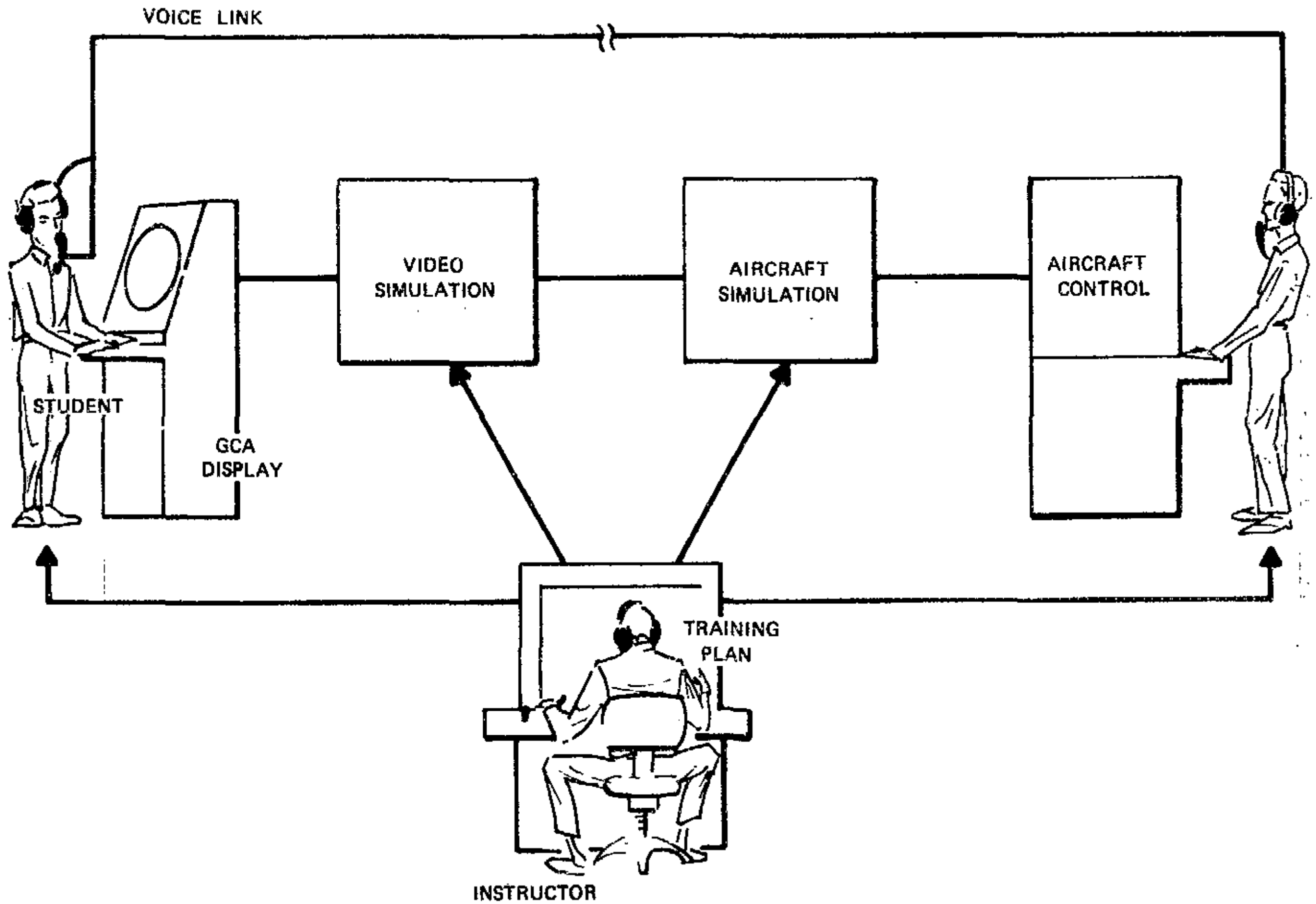

Figure 1. Existing GCA Controller Training System

based on the very latest technologies as represented in:

a. Training requirements analysis

b. Automated adaptive training

c. Optimally structured computer programming

d. Machine understanding of spoken commands.

Approach

The plan of this work calls, first, for the creation at the Naval Training Equipment Center of an experimental laboratory version of a training system for teaching students controllers the PAR phase of the GCA. This facility will be used to explore all important aspects of the technical feasibility of the concept. At an appropriate time the laboratory findings will be translated into a design to be implemented and tested at the Navy's GCA Controller school. Using the experience gained from the field examination, a training system for at least one other controller-type job will be designed and evaluated. The final product, if warranted, will be a specification for the incorporation of these techniques in the design of future training systems.

GCA CONTROLLER TRAINING SYSTEM

System Design

Design of the system began with a study by Logicon, Inc. under contract to the Naval Training Equipment Center. The product of this effort was a report that confirmed the conceptual validity and presented a functional design of such a system. The broad outline of this design is shown in figure 2. To relate this to the more familiar block diagram of Adaptive Training Systems, we point out that the Speech Understanding Subsystem and Student Speech Evaluation Subsystem are, properly, components of the Performance Measurement Subsystem. The Adaptive Syllabus Control Subsystem corresponds to the Adaptive Logic Subsystem and the Training Control Subsystem together with the GCA Display provide the Adaptive Variable or Controlled Element Subsystem.

Under this design, in his first session, a student would be prompted to give samples of his speech for each of the phrases in the GCA set. Reference patterns for these elements would be stored on cassette tape and be automatically retrieved at the start of each subsequent session. On the same, or perhaps a separate, cassette would be recorded data on the student's performance as a controller during a session. A session would consist of a sequence of simulated GCA runs. The runs would be drawn from a problem pool graded in difficulty and constituting the training syllabus. Selection would be based on a difficulty level requested by the adaptive logic, which, in turn, would derive its choice from data furnished by the performance measurement subsystem. During a PAR descent the student would speak advisories for capture by the speech understanding subsystem. The phrase understood would be passed to the Training Control Subsystem where an aircraft and pilot dynamics model would effect changes in the movement of the aircraft as represented on the simulated radar display. Simultaneously, the phrase would be passed to the Student Speech Evaluation Subsystem for processing to produce at the end of the run an analysis and evaluation of the student's vocal performance and overall system performance. These data would, in turn, be passed to the Adaptive Logic for use as described above. These data would also furnish the basis for feedback to be given to the student at the end of each run.

In the sections that follow we will report progress to date on each of the major components of the system we have just described.

SPEECH UNDERSTANDING SUBSYSTEM

Approach

Although, as stated earlier, we view machine understanding of speech simply as one of the necessary steps to reach the larger goal of objective, automated adaptive instruction, nevertheless, a disproportionately large part of the research has been and will be directed to acquiring this capability. The emphasis stems from the fact that it is the least developed of all the technologies involved. Since we are not devoted to speech understanding research for its own sake, our approach is to adopt whatever combination of hardware and software, algorithms and heuristics, theoretics and pragmatics, will get the job done for this application. As a result, the subsystem will evolve as a two-stage process.

Acoustic Features Stage

The first or Acoustic Features stage will be built around a speech recognition system, the VIP-100, purchased by the Naval Training Equipment Center from Threshold Technology, Inc., Cinnaminson, New Jersey. As delivered, the VIP-100 is able through a mix of hardware and software processing to accept a spoken utterance of up to two seconds duration, compare it to each of up to 128 pre-stored patterns for a particular speaker, and report either a match or failure to reach the criteria for a "good" match.

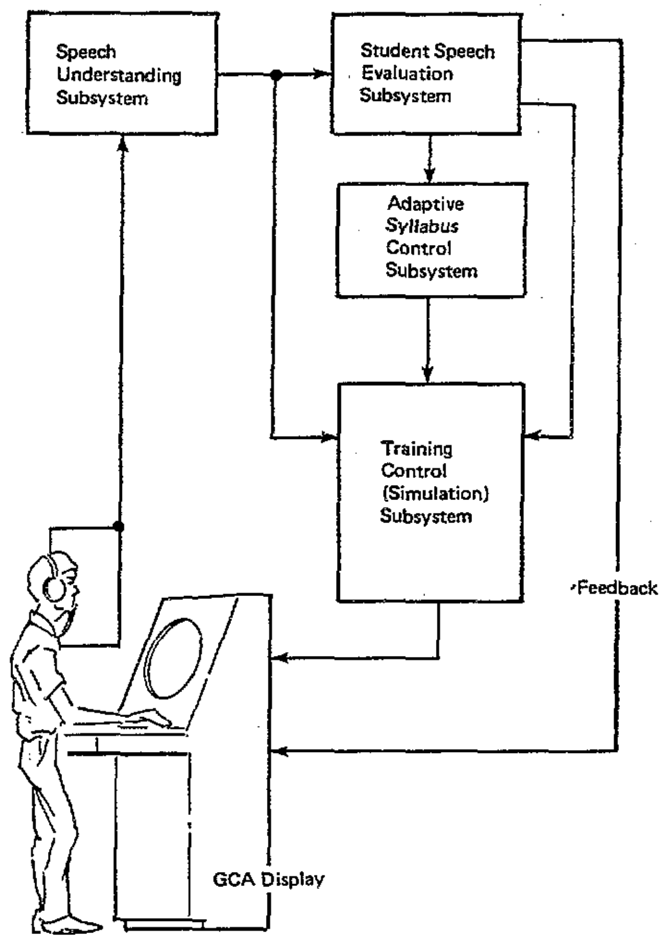

Figure 2. Proposed GCA Controller Training System

The incoming speech signal is sampled every two milliseconds by special circuitry which decides on the presence or absence of 32 features used to characterize the acoustic energy. The successive binary samples are stored in a core memory buffer of a digital computer until the end of the utterance is marked by the setting of a feature termed Long Pause. Since the number of samples entered will vary with the duration of the phrase, the data are then time normalized with a computer program which reduces the buffer to a standard size Features Array by grouping the primary data and using a "vote" logic to determine whether a feature will be set in the secondary buffer.

During a pre-training phase, a speaker voices several repetitions of each phrase in the selected set. The Feature Arrays for each of the repetitions of a particular item are then combined through another voting process in a single Reference Array representing that phrase. In recognition mode when a phrase is spoken, its Feature Array is formed and compared to each of the Reference Arrays in the set. A score is calculated for each comparison by assigning different weights to the four possibilities that arise from the presence or absence of a feature and from the agreement or disagreement of the compared arrays. All phrases whose Reference Arrays when tested against an incoming Features Array yield a positive score above a programmable threshold are considered candidates for selection. If the highest scoring phrase exceeds the next highest positive score by a required margin, the top scorer is immediately chosen as the phrase recognized. If the minimum difference does not exist, all positive scores at or above the threshold are reported. If no phrase reaches the threshold, the system indicates "rejection".

The standard VIP-100 has been demonstrated to provide an overall recognition accuracy at between 85 and 90 per cent. Under a follow-on contract to the original study, Logicon, Inc. has been developing a number of software modifications that promise to raise the accuracy of the Acoustic Features stage to around 95 per cent. Tests are underway to see if reliable differences in accuracy occur for an individual over a period of weeks, to see if there are differences between individuals in the average accuracy recorded, and to explore why some phrases are harder than others for the machine to recognize.

Recognition Assistance Stage

Now, obviously, even 95 per cent accuracy is unsatisfactory for our purposes. Therefore, we have introduced a second or Recognition Assistance stage. The candidate phrases, that is, all phrases which exceed some threshold value for a "good" match, will be further processed by software which will screen them against a small set of "expected" phrases. The "expecteds" will be generated by consideration of what advisories would be appropriate given the recent history of aircraft position during a run. The outcome of the Recognition Assistance stage, including failure to recognize, will be passed to the Training Control and Student Speech Evaluation Subsystems. The Recognition Assistance program is still under design and must be carefully thought out, since its success will determine whether we can reach the desired goal of 99 per cent understanding accuracy. Clearly, a high level of positive identifications must not be gained by admitting many false positives.

Types of Error

At this point it might be useful to dwell on some of the types of errors that can arise in the understanding situation and their impact on the total training system. An obvious distinction should be made between student errors and errors by the Speech Understanding Subsystem (SUS). A student can err by:

a. Using a phrase not in the set of acceptable phrases

b. Using a valid phrase but in inappropriate circumstances

c. Failing to adhere to required procedures

The SUS can err by:

a. False negative understanding, that is, failure to identify a valid phrase whether or not appropriate. Unfortunately, there is no way to distinguish rejections of valid phrases from those due to invalid ones except by checking audio recording of the speech.

b. False positive understanding, that is, on the one hand, selecting a valid phrase when the input was invalid and, on the other, selecting a valid, appropriate phrase when the input was inappropriate.

As regards the effect of errors on the simulation dynamics and student's radar display, failures of the SUS to identify the input should be inconsequential provided a request for repetition is honored without excessive delay. Similarly, false positives if infrequent should have no major impact on aircraft position changes.

The consequences of student and SUS errors are more serious for the Student Speech Evaluation Subsystem. Here it is important that SUS errors not obscure student errors due to confusion and faulty judgment. In particular, the SUS must guard against losing a "true" input when it comes close to a different, more highly "expected" advisory. Hopefully software routines can be developed that are sensitive to these possibilities, so that the Student Speech Evaluation Subsystem will receive an accurate reflection of the student's input.

STUDENT SPEECH EVALUATION SUBSYSTEM

Data for Evaluation

No less vital to the success of this venture is the development of a subsystem for the classification, analysis and evaluation of student performance. Although present PAR controller performance measures are largely subjective, the syllabus used by the Navy at NAS Glynco provides guidelines for developing objective measures. Additional background data for performance measurement was collected at NAS Miramar. The end result was a list of measures falling into two classes:

a. System output indices, such as:

1. Measures based on the track history of the aircraft about the glidepath

2. Measures based on the track history of the aircraft about the extension of the runway centerline

b. Student control input measures, such as:

1. Elapsed time between advisories

2. Percent phrases rejected due to student error

3. Percent correct (valid and appropriate) advisories

4. Distribution of advisories among categories and subcategories

5. Ratio of glidepath to course advisories

6. Distribution of N-degree heading changes

7. Count of procedural errors and required advisories omitted.

Experimental and simulation studies will be conducted on the above set of measurement sources. They will be examined for redundancies and their ability to differentiate quality of performance. Some may be dropped. Other data transforms may be added. A guiding principle will be to find the minimum combination that can discriminate among performances and, hopefully, to predict later performance based on earlier performance so as to enable early remediation.

Scoring, Recording and Feedback

Three types of output are required of the Student Speech Evaluation Subsystem. The first of these is a single composite score derived from the types of measures listed just previously. This score will be used by the adaptive logic to select the difficulty level of the next problem. The second category of output includes both hard copy printout of all data that identify and summarize a run and data for the individual student file maintained on magnetic tape cassettes. The latter will make possible automatic continuity of training from session to session. The foregoing techniques have been successfully implemented elsewhere (2, 3, 4) and can be adopted with only minor changes. The third type of output would be those data that would make possible immediate qualitative and quantitative feedback to the student on his performance.

ADAPTIVE SYLLABUS CONTROL SUBSYSTEM

Training Syllabus

The Adaptive Syllabus Control Subsystem (ASCS) has been conceptualized as consisting of a training syllabus and the adaptive logic used to select the next training program. A preliminary syllabus has been designed which contains a set of PAR runs or problems arranged in a sequence of increasing difficulty. The difficulty level of a run is a function of the difficulty level set for each of the adaptive variables whose states govern the conditions of the run. Several values representing points along a continuum of difficulty were identified for each of the four variables described below:

a. Wind Factor

Level 1 - no wind
Level 2 - 10 kts at 30°
Level 3 - 20 kts at 30°
Level 4 - 10 kts at 90°
Level 5 - 20 kts at 90°

b. Aircraft Type

Level 1 - 90 kts at 21,000 lbs (FAA Category A)
Level 2 - 120 kts at 31,000 lbs (FAA Category B)
Level 3 - 140 kts at 61,000 lbs (FAA Category C)
Level 4 - 166 kts at 151,000 lbs (FAA Category D)
Level 5 - 220 kts at 200,000 lbs (FAA Category E)

c. Pilot Response

Level 1 - optimum response
Level 2 - average response
Level 3 - below average response
Level 4 - poor response

d. Pilot/Aircraft Variability

Level 1 - no error
Level 2 - modify vertical speed ($\dot{n}$) by a random number ($-1 \leq N \leq 1$) times 100 ft. per min.
Level 3 - modify heading rate ($\dot{x}$) by a random number ($-1 \leq N \leq 1$) times .5 deg. per sec.
Level 4 - combination of Levels 2 and 3

The choice of level combinations and their ordering on a continuum of difficulty to furnish a syllabus of sixty runs was done on the basis of analytic judgements. The syllabus is highly tentative. Laboratory testing will be done to verify the correctness of the difficulty assessments, to ascertain whether the range of difficulty encompassed is adequate given training and operational considerations, and to examine the linearity of the difficulty scale in order to evaluate the importance of an equal-interval scale.

Adaptive Logic

The current design calls for the use of an adaptive logic which is essentially the same as that employed in several other adaptive training modules developed by the Naval Training Equipment Center (2, 3, 4). The selection of the next problem run presented to the student will be based on the score generated by the Student Speech Evaluation Subsystem for the run just completed and on the change in difficulty level used to select the immediately preceding run. The latter factor enables the procedure to be "adaptive-adaptive" since a series of successful runs can accelerate the student through the syllabus. This carries out the principle of individualized instruction by permitting the "better" student to complete his training in a shorter time, that is, after fewer runs. Similarly, the "slower" student will receive additional runs at downward-adjusted levels of difficulty. Unless an instructor intercedes, all students must successfully complete the run representing the highest level of difficulty in order to "graduate" the course.

TRAINING CONTROL SUBSYSTEM

The Training Control Subsystem will be at the heart of the automated adaptive capability. As such, it will take the problem selected by the Adaptive Syllabus Control Subsystem, initialize the problem, generate and control the Precision Approach Radar display, convert the output of the Speech Understanding Subsystem into formats acceptable by the Aircraft/Pilot Simulation, implement the adaptive variables, and, in general, control the progress of the run from its start to its end point whether over threshold or missed approach procedure. Two major functions of the Training Control Subsystem deserve further description. These are the Aircraft/Pilot Simulation and the Precision Approach Radar display. The design and implementation of these two functions are being done in-house by staff of the Human Factors Laboratory.

Aircraft/Pilot Simulation

For purposes of the experimental laboratory version of the training system it has been assumed that generalized, simplified aircraft/pilot equation models will be adequate. The function of the equations for glidepath and course or ground track is to incorporate the effects of the adaptive variable levels prevailing for the run, operate on the transforms of the student advisories supplied by the Speech Understanding Subsystem, transmit range, altitude, and centerline deviation data to the PAR display generation function, and maintain aircraft position and velocity data for passage to the performance measurement and recording functions of the training system. As far as the student viewing the PAR display is concerned it is necessary only that the aircraft "blip" change position in a "realistic" manner. Therefore detailed equations for particular aircraft are not needed for the initial version of the training system. At this writing a preliminary set of equations has been designed and implemented which responds rather well to positional advisories for glidepath and course. To these must be added the ability to deal with rate information and with heading commands. Also, the stability of the aircraft position is somewhat greater than would normally be seen and some kind of perturbing factor should be added.

Precision Approach Radar (PAR) Display

Since the literature on transfer of training is not in agreement on what, other than physical fidelity, constitutes "similarity" of stimuli, the easy way out is to reproduce, within limits of time and cost, the visual presentation that will confront the student in the operational situation. For our laboratory version we will use a general-purpose, refreshed point plotting CRT display to simulate the image presented to the students on the AN/CPN-4 systems used at the GCA school, NAS Glynco, Georgia. The PAR display is actually two separate radar presentations combined on a single 12" screen. The upper portion is the elevation display (EL) while the lower is the *azimuth display* (AZ). Range and Ground Point Intercept (GPI) marks are on the same vertical scale. The elevation display covers 56^{o} (7^{o} of antenna scan) and the azimuth display covers 52^{o} (20^{o} of antenna scan). Range scale is selectable and is usually set to show about 10 miles on final approach. The glidepath cursor as a rule marks a two and one-half to three degree glide slope. This implies a glidepath intercept altitude at around 2200 feet. A logarithmic time base sweep is used on the AZ-EL indicator to give greater emphasis to more critical, close-in targets. Thus, the glidepath cursor appears slightly curved on the scope although it represents a straight line in space. The first few range marks are comparatively far apart and the more distant ones are comparatively close to each other. An aircraft will appear to pick up speed on its approach as its range decreases.

An approximation of the AZ-EL display has been implemented on a Digital Equipment Corp. Type 339 Buffered Display, which is a component of the Human Factors Laboratory's ADCONS facility. It simulates the presentation described above, differing only in certain scale factors and in the absence of ground clutter and precipitation returns. In addition, a number of training-related messages will be presented to the student by means of the 339.

SUMMARY AND CONCLUSION

The foregoing sections have sketched the rationale for and general design of an experimental training system based on automated adaptive principles for instructing student GCA controllers in the PAR phase of the final approach. The purpose of the laboratory facility will be to check out the functioning of the component subsystems and the overall training effectiveness of the total system. To this end it will be necessary to examine whether the technical solutions implemented fulfill the requirements that follow.

a. *Speech Understanding Subsystem*

1. Recognize speech inputs from the GCA phraseology automatically (in real time) with less than one per cent rejections.

2. Discriminate advisories which affect the aircraft simulation from those that do not.

3. Discriminate glidepath advisories from heading advisories.

4. Translate all advisories (with numerical values) into output terms acceptable to the Student Speech Evaluation Subsystem and those that affect the control of the aircraft *into terms acceptable to the Training Control* (Simulation) Subsystem.

b. Student Speech Evaluation Sybsystem

1. Generate the minimum number of performance measures required for prediction and diagnosis.

2. Generate a single score descriptive of performance on a run for the Adaptive Syllabus Control Subsystem.

c. Adaptive Syllabus Control Subsystem

1. Provide a syllabus exhibiting adequate problem coverage, difficulty range and difficulty resolution.

2. Provide an adaptive logic that maintains stable control and exhibits sensitivity to individual training needs.

d. Training Control (Simulation) Subsystem

1. Utilize the simplest (most quickly computed) set of equations that adequately represent the influences on aircraft control.

2. Generate the minimum visual presentation equivalent to the information content available to the student controller through the PAR display.

3. Provide for automatic initiation and termination of runs and sessions.

e. Total Experimental Facility

1. Provide means to assess effect of system on student motivation.

2. Provide capability to function in non-adaptive mode.

3. Provide capability to accept student input through means other than speech subsystem.

4. Provide means for "instructor" intervention.

The last four requirements, obviously, are intended to make possible studies to establish whether the system design implemented, beyond be able to "run", is able to train better than other designs lacking the full automated adaptive capabilities.

The purpose of this paper, in keeping with the spirit of th Industry Conference, has been to make you aware of our interest and activity in this area. Although we are hopeful that the Speech Understanding Subsystem will prove adequate, we are particularly interested in any ideas you may have on speech understanding technology. Of course, your suggestions on any and all other parts of the project are most welcome.

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ABOUT THE AUTHORS

MR. IRA GOLDSTEIN is a Research Psychologist in the Human Factors Laboratory at the Naval Training Equipment Center. His professional activity over the past dozen years has focused on the role of computers in behavioral science research and their employment to improve training. He has contributed a number of technical papers on computer-controlled measurement of human performance in perceptual-motor and decision-making tasks. Before joining the Center in 1969, Mr. Goldstein was employed in private industry for 4 years. Previously, he had been with the United States Air Force's Decision Sciences Laboratory from 1958 to 1965.

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DR. JOHN P. CHARLES, Senior Human Factors Psychologist at Logicon, has a broad background in systems design, from requirements analysis and definition to system test and evaluation. Since coming to Logicon, Inc. in 1969, he has concentrated on the human factors aspects of projects ranging from automated adaptive training systems to advanced gaming of conflict and disorder situations. As Principal Investigator for contracts with the Naval Training Equipment Center, he has been studying the feasibility of an Advanced Ground Controlled Approach (GCA) Controller Training System based on automated speech understanding and automated adaptive instruction. From 1951 to 1969 he served as an officer in the U.S. Navy, during which time he held a number of positions involving high-level human factors responsibilities. Dr. Charles has authored numerous technical reports and meeting papers.

DR. ROBERT L. FEUGE, a Psychologist at Logicon, has an extensive knowledge of training which ranges from theory and principle of transfer research to training device design, to computer-aided instruction including trainer effectiveness evaluation. During the past 5 years, Dr. Feuge has designed, implemented, and evaluated the personnel subsystem aspects of a variety of training devices for the Air Force and Navy, as well as conducted fundamental research on advanced training technology. Dr. Feuge is either author or co-author of a number of professional articles, mainly concerned with training and transfer of training. At Logicon he has been engaged in development of the speech understanding subsystem for a proposed Ground Controlled Approach Controller Training System. From 1968 to 1973 he was employed by Honeywell, Inc. in the development of training devices for the U.S. Navy and U.S. Air Force.

MR. MICHAEL W. GRADY, Programmer Analyst, has been with Logicon, Inc. since 1969. His efforts have been directed to software development for a variety of simulation and real-time training systems with special emphasis on sensor subsystems. These include, for the U.S. Navy, a proposed Ground Controlled Approach Controller Training System (GCACTS), Warfare Analysis and Research Systems (WARS), Tactical Advanced Combat Direction and Electronic Warfare (TACDEW) System and, for the U.S. Air

Force, an Automated Instrument Flight Training System. Prior to joining Logicon, Mr. Grandy spent a year at the Institute for Pure and Applied Physical Problems. From 1964 to 1969 he was at the Crocker Nuclear Laboratory as research assistant and operator of Cyclotrons.

MRS. MARY H. BARKOVIC, a Programmer Analyst, has worked with a broad spectrum of computers from large scale to a variety of minicomputers. While at Logicon she has participated in software development for several U.S. Navy research, training, and operational systems, such as the performance measurement and adaptive logic subsystems of a proposed Ground Controlled Approach Controller Training System (GCACTS), an Automated Adaptive Instruction Module for Device 2F90, and mathematical models used by the Fleet Combat Direction Systems Support Activity, San Diego.