ADAPTIVE TRAINING DEMONSTRATIONS — LESSONS LEARNED

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Over the past few years, LOGICON has conducted a series of studies for the Naval Training Equipment Center concerned with exploiting and applying advanced training technology to weapon system trainers. The first study included a review of an existing Airborne Weapons System Trainer (AWST) and a survey of training and related digital computer technology. Three subsequent studies demonstrated advanced technology applications to a basic, intermediate, and advanced air training task. Much was learned in these technical demonstrations and will be summarized in the succeeding paragraphs. First the nature of each of the demonstrations will be reviewed and then some of the major "lessons learned" will be discussed.

The first study was conceptual in nature and began with a brief review of a typical fighter AWST. The review revealed that in large:

1. AWSTs were being used as procedure trainers

2. There was no integrated training plan or syllabus

3. There was no objective performance or criteria measurement

4. The instructor's role was ill defined.

The last part of the study was a survey of training methodology and trainer computer technology. The conclusions exceeded initial expectations. It was pointed out that even routine state-of-the-art technology, if applied, could conceptually improve training significantly and unburden and aid the instructor. Furthermore, existing technology could permit effective implementation of advanced developments in training methodology.

Intermediate Training Task — GCA

Next a demonstration study was undertaken to demonstrate that the conclusions reached in the survey study were technically feasible. The results were reported at the last conference. It involved development of an automated adaptive training system employing a computer-controlled voice and was implemented using the TRADEC research simulator at NTEC. The system provided for:

- Student identification and briefings

- Student recordkeeping

- Precision approach control training through a wide spectrum of aircraft and environment conditions employing an automated final approach controller model
- Objective performance measurement
- On-line restructing of the syllabus for each student based on performance
- A graphics terminal for instructor monitoring

Basic Training Task — Basic Instrument Flight Maneuvers

The study of automated adaptive GCA training successfully demonstrated that advanced training methodology and technology could be applied to a well defined flight segment or intermediate flight task. Furthermore, it was acceptable to operational pilots. However, performance criteria, system characteristics and constraints are well defined for the GCA, and the student has already acquired the basic flying skills required for the tasks. Therefore, another study was undertaken to see if similar advanced methodology and technology could be applied to a basic training task. Instrument Flight Maneuver training was selected.

The instrument maneuvers began with straight and level flight and progressed through climbs and dives, level turns and climbing-diving turns or vertical maneuvers. A syllabus of 82 exercises was constructed using 3 aircraft weight conditions and 3 levels of turbulence. Constant air speeds, vertical speeds, bank angles, and turn rates were also included. Performance requirements were based on jet aircraft NATOPS standards. A measurement scheme was developed which essentially accumulated the root mean square error about the assigned parameter for the maneuver. Verbal instructions and feedback were provided to the student by a computer-controlled voice system. A typical monitoring and output module is flowcharted in Figure 1. The module was used in all exercises where heading control was a basic parameter for the maneuver. The NATOPS performance standards data had indicated the holding heading within $\pm 10^{\circ}$ was acceptable for jet instrument flying. This value was assumed to reflect a two standard deviation (SD) value. For instruction purposes, performance within $\pm$ 1 SD of the parameter was considered excellent and no verbal instruction to the student was required. If control of the parameter varied between 1 and 2 SD, the module would output a "check heading" instruction, for example. If control further deteriorated and parameter control exceeded two SD but less than 4 SD, an instruction giving the corrective action was output. Finally, if the error exceeded 4 SD, the exercise was frozen and the reason output.

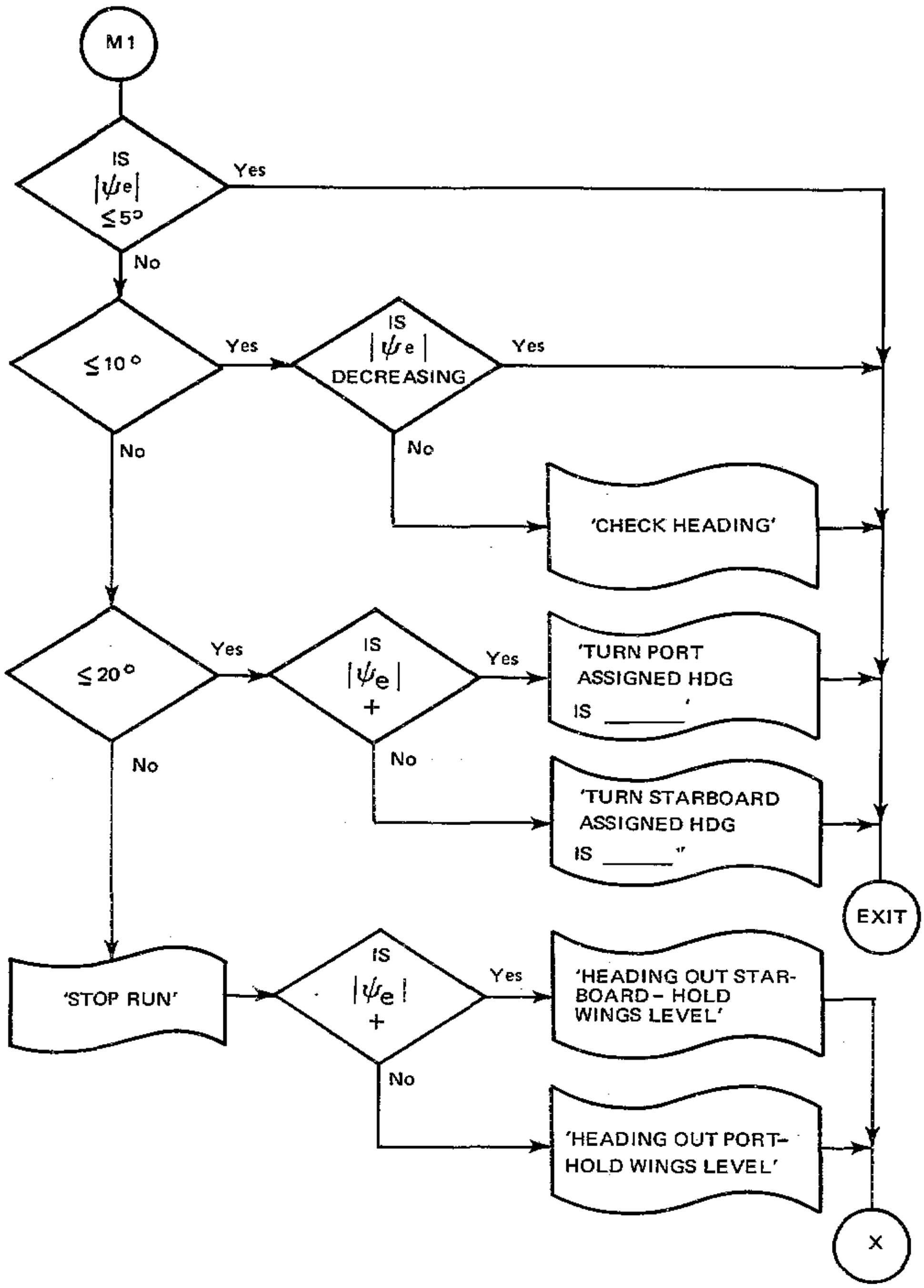

Figure 1. Heading Error Monitoring Module

Table 1 shows the "bands" used for each of the six parameters monitored. An adaptive training algorithm similar to that used in the GCA study was implemented to select the characteristics of the next exercise. Again an "adaptive-adaptive" scheme was employed. A display on a graphics terminal was developed for future instructor use. Figure 2 shows a typical display. Hard-copy data of each exercise was also output.

Table 1. Parameter Limits

Parameter	Inner	Middle	Outer
Heading (ψ)	$\pm 5^{\circ}$	$\pm 10^{\circ}$	$\pm 20^{\circ}$
Altitude (h)	± 100'	± 200'	± 400'
Airspeed (ν)	± 0.02 Mach ± 5 kt	± 0.04 Mach ± 10 kt	± 0.08 Mach ± 20 kt
Vertical velocity ($\dot{h}$)	± 250'/sec	± 500'/min	± 1000'/min
Turn rate ($\dot{\psi}$)	$\pm 0.5^{\circ}$/sec	$\pm 1.0^{\circ}$/sec	$\pm 2.0^{\circ}$/sec
Angle of bank (ϕ)	$\pm 2.5^{\circ}$	$\pm 5^{\circ}$	$\pm 10^{\circ}$

The project was implemented on the TRADEC facility at NTEC. Three NTEC staff members were "trained". Although time precluded all students completing the syllabus, all succeeded in reaching the most difficult exercise level. This was accomplished in 6-8 simulator sessions (the aircraft simulated was a F-4E)!

Advanced Training Task — GCI and Air-to-Air Attack

The last study was concerned with an advanced training task. An air-to-air intercept from a vector mode such as CIC or GCI was selected. The computer-controlled voice system was utilized in the simulation of both the ground controller and Radar Intercept Officer (RIO). Head on, beam, and stern conversions were implemented into a syllabus which also used aircraft weight and atmospheric turbulence as adaptive variables. Three different vectors from takeoff were implemented. The entire mission was divided into three phases:

a. Takeoff and vector to target acquisition

b. Attack, which included two subphases

- Acquisition to lock-on using RIO input
- Lock-on to break-away using a steering dot display

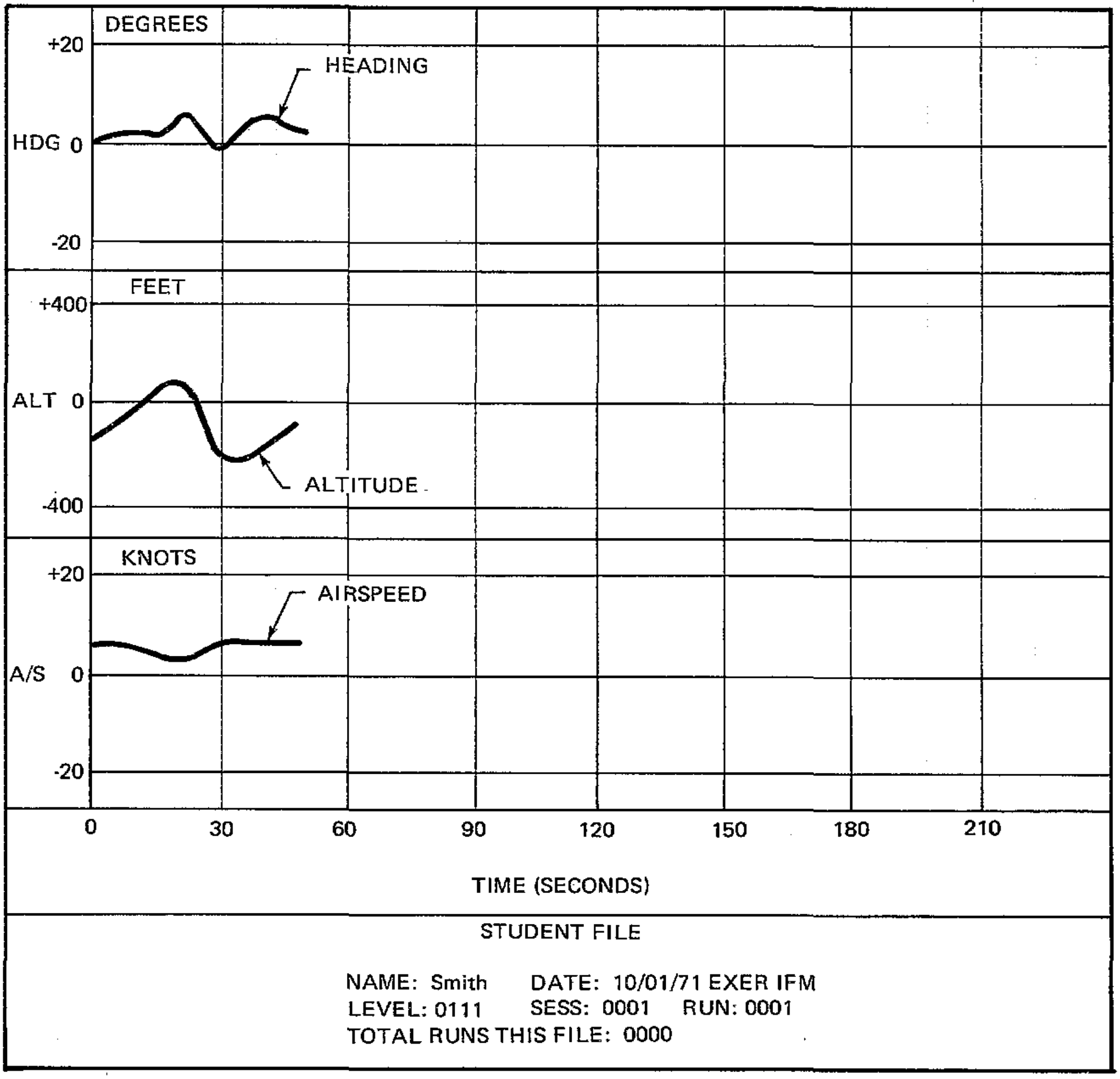

Figure 2. Typical Instructor Display of Parameter Errors

c. Descent to landing.

The performance measurement routines utilized the "band" approach developed in the IFM study but included "gate" position data for entry to target acquisition, lock on, and firing. The gates reflected typical airborne radar limits. Standard Navy brevity code was employed for the voice system. An instructor's display was generated on a graphics terminal for each phase of the mission for possible future use. An adaptive algorithm was used to restructure the syllabus based on pilot performance. Since the attack phase was much more difficult than the vector phase, a re-attack routine was developed to extend practice in the attack phase. Thus approximately equivalent difficulty level could be maintained for all three phases during the training. The final report is in preparation and should be available shortly.

Lessons Learned

It is most important to bear in mind that these studies were technical feasibility demonstrations and not evaluations; i.e., no operational training was conducted and no transfer of training experiments were conducted. This remains to be done and is justified in view of the success of the studies. Evaluations, with instructors in the environment, are also needed since one of the goals was the unburdening of the instructor.

Aside from successfully technically demonstrating automated adaptive training across a wide spectrum of training tasks, the studies also revealed many facets to implementing advanced training methods.

Each of the three training studies involved development of fully automated and adaptive training. Each of the training programs was designed so that the entire syllabus could be implemented by the computer. The student was only required to enter his name via the keyboard at the start of each training session. From that point on, all briefings and instructions were automatic, including flight clearances. Aircraft configurations were monitored and procedural errors called to the attention of the student. The programs were designed so that in no case was a student ever "lost" by the system even though he crashed, failed to appear at a Final Approach Fix, GCA final or tried to lock-on beyond radar limits.

> Lesson Learned #1. Careful flow charting of student activity in the training situation being developed can successfully provide for unforeseeable student behavior and exercise outcome contingencies.

The key to adaptive training is performance measurement. Unless student performance on the task can be quantified and summarized, automatic on-line restructuring of the syllabus based on that performance is impossible. Measurement of pilot performance is a controversial subject. Many dollars and much time has been spent by many agencies and competent researchers to define and measure pilot performance. Much remains to be done before the problem is solved. However, based on the studies completed, it is our belief that training, particularly in flight simulators, need not wait for the ultimate answer. Two major reasons can be cited. First, the ultimate product is not specific human performance, but total system performance, and second, knowledge of human performance appears adequate to meet the relative course resolution requirements for weapon system trainers. System performance in a specific operational environment can normally be quantified. For example, the system performance requirements for a GCA precision final approach are readily quantified and usable for training criteria. Our analyses revealed that similar criteria are generally available, at least for the type of flight missions utilized in our studies. Thus, although the transfer studies have not been done, we are convinced, at this point, that meaningful quantified performance criteria can be developed for adaptive training control purposes.

> Lesson Learned #2. Existing performance measurement capability coupled with analysis of system performance requirements for the relevant mission can provide quantitative data for adaptive training implementation.

A single score summarizing performance is required for input to the adaptive logic routine. The approach used in our studies involved straightforward normalizing and averaging of the data. Differential weighting factors were easily estimated by analysis and adjusted during pilot runs. Again, no experiments were conducted in an operational training environment to validate the approach. However, the demonstration results indicate that the techniques used probably have adequate sensitivity for automated adaptive training control purposes.

> Lessons Learned #3. Normalizing and averaging performance data appears to provide adequate resolution for training control. Weighting factors can be analytically derived and empirically adjusted, especially when system performance is utilized as the criteria.

Adaptive algorithms were utilized in each of the three studies to select conditions for the next trial. The routines were actually adaptive-adaptive in that progress could be accelerated as a function of the change effected in the previous trials. The adaptive training implemented was intertrial; i.e., no change to the difficulty of the task was implemented during a "run". Table 2 summarizes the logic tables for the three studies. The table for the first study reflected our initial concern about stability. The concern proved unwarranted; i.e., in no case was exercise level oscillation encountered. Further study and refinement of this type of algorithm should be conducted.

Table 2. Adaptive Logic Tables — Syllabus Change Values

Previous Run Increment Status	Score				
	↓50	50-100	100-150	150-200	200↑
-Decremented	-4	-2	0	+1	+3
0 no change	-3	-1	0	+1	+3
+ Increment	-2	-1	0	+2	+4

GCA

Previous Run Increment Status	Score				
	↓50	50-100	100-150	150-200	200↑
-	-3	-2	0	0	+1
0	-2	-1	+1	+1	+2
+	-1	0	+1	+2	+3

IFM and GCI/Air-to-Air Attack

Lesson Learned #4. Simple adaptive algorithms for on-line inter-trial syllabus development can be employed and appear to be effective.

The identification and selection of meaningful adaptive variables has been the subject of much discussion. The major point of controversy has revolved around the possibility of achieving no transfer or negative transfer of training as a result of modifying the training situation. For example, introduction of a difficulty factor or variable not found in the operational environment could modify the task so that the student learned responses inappropriate or inconsequential to the actual mission. Fortunately, in all our studies, mission analysis revealed a large number of variables which could be used for adaptive training which would exist in normal operations. Thus the problem was not one of creating artificial adaptive variables, but of culling the more meaningful variables from the large set that was found to occur in typical system operation. The selection process was simplified in our studies by the capabilities of the TRADEC simulation facility. Thus we utilized weight and atmospheric turbulence along with inherent mission or flight task difficulties because they could be implemented readily in the TRADEC. They were also analytically and intuitively logical variables since they significantly altered the control task.

Lesson Learned #5. Meaningful adaptive variables probably exist for all flight missions. Therefore, introduction of artificial secondary tasks for adaptive variables should not be required. The range of values for the adaptive variables can also be determined analytically through mission and environment analyses.

Learning or acquisition rates vary significantly, even for the limited sample of "students" used in the demonstrations. Perhaps the most meaningful data in terms of operational training came from the GCA study in which pilots, actually transitioning to the F-4E aircraft, were "trained". Figure 3 shows the progress of some of the pilots through the syllabus. The plots are typical of those found in the other studies in that progress through the syllabus varies with each student. Furthermore, the difficult aspects of the tasks appear to vary with each student.

Lesson Learned #6. Adaptive training of the sort used in these studies appears to allow the student to progress at his own speed, practicing new or difficult aspects of the task as necessary. This is the goal of individualized training and appears to have been achieved with the approach utilized in these studies.

Acceptance of a training situation by the student, followed by dedicated or motivated effort is essential to efficient training. Although additional data in an operational environment will be required for verification, the studies conducted indicate that automated adaptive training is accepted by pilots, and more importantly that motivation is high in this type of training situation. Results of debriefings and post-exercise questionnaires all revealed that the tasks were stimulating and challenging to the student. The sustained effort by the student's in the studies is mute evidence of this effect.

Lesson Learned #7. Adaptive training, of the type used in these studies, increases the motivation of the student.

Both cassette tape recorders and a computer-controlled speech generating system were employed. The cassette tape system was used for long briefings and proved satisfactory. The speech generating system was one of the first devices developed. The speech was generated by selecting

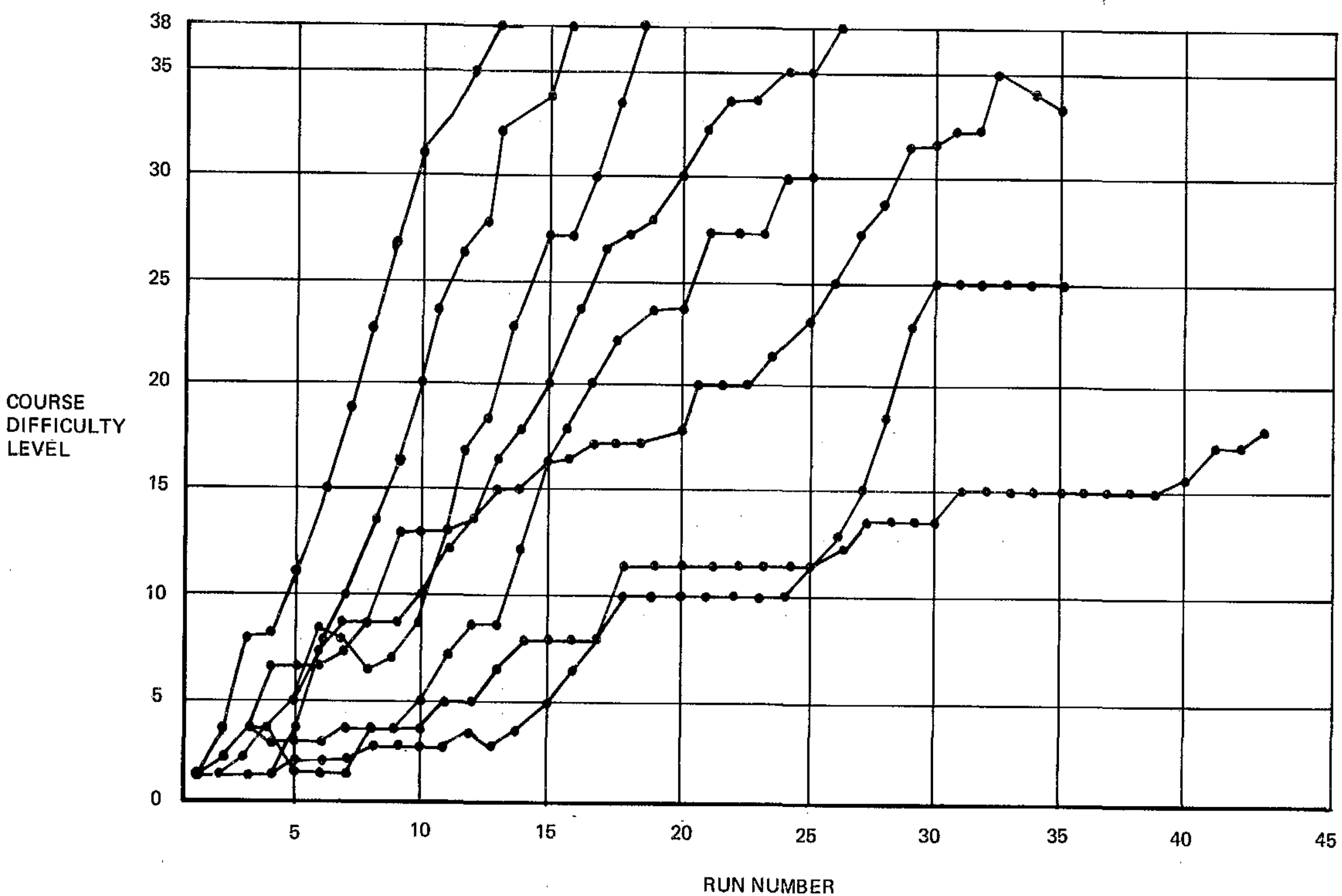

Figure 3. Plot of Runs by eight F-4 Pilots on GCA Exercise

and outputting words recorded in fixed 1/2-second time "slots". The resultant speech has a fixed inflection and is stylized by the 1/2-second time slot for each word (regardless of length). Yet in spite of these shortcomings, the voice was acceptable to the pilots in the GCA study and to the demonstration "students" used in the other studies. The uniqueness of the speech was apparently forgotten or easily adjusted to in the first few trials. Overall, the speech system provided a highly flexible means of providing verbal input to the student, both for instruction purposes and for simulation of GCA and CIC/GCI commands.

> Lesson Learned #8. Computer-controlled speech systems can be utilized to provide verbal input to the student both for simulation of instructor functions and other functions requiring voice instruction or commands to the student. The use of conventional audio techniques (tape recorders) under computer control for relatively long briefings or explanations is state-of-the-art.

<u>Summary</u>

Overall, the three demonstrations of automated adaptive training ranging from basic instrument flight training tasks to air-to-air intercept tasks were successful. The data indicates that:

- Training economies can be realized,
- Student motivation can be increased,
- Training scope can be expanded,
- Objective performance data can be developed, and
- Unburdening of the instructor can be achieved.

The latter point is considered particularly important since the instructor can be freed to observe the student's behavior and provide the necessary assistance. He need no longer devote full time to operation of a complex trainer, much less managing and directing the syllabus through a maize of switches, knobs and dial settings. Of more importance, however, was the general result that existing training knowledge can be brought to bear on simulation training problems with potentially significant impact. There is little doubt but that adaptive techniques based on objective performance measurement can decrease training time and improve learning. The instructors can be unburdened and permitted to help shape the student's behavior. Uniform training output can be achieved by requiring objective demonstration of criterion performance.

ABOUT THE AUTHORS

DR. JOHN P. CHARLES, the Senior Human Factors Engineer at Logicon, has a broad background in Navy weapons system R&D. He has been responsible for the advanced development projects on automated-adaptive training conducted for the Naval Training Equipment Center and other defense agencies. The PhD was awarded at Northwestern University. Broad experience in aviation R&D was accumulated through 20 years as a Naval Aviation Experimental Psychologist. The experience ranged from active flying as a Technical Observer to manager of human factors research and development laboratories.

MR. ROBERT M. JOHNSON, Senior Programmer Analyst at Logicon, has an extensive background in the design and implementation of real-time computer programs, especially in the area of simulation and training. He has been singularly responsible for the design, implementation and validation of the automated-adaptive training programs in the studies conducted for the Naval Training Equipment Center. His broad background in design, implementation and validation of programs across a broad spectrum of programming languages and techniques has contributed immeasurably to the success of the automated training programs.