

0012-134



HumRRO INTERNATIONAL INC.
a subsidiary of the Human Resources Research Organization

ATC TRAINING ANALYSIS STUDY: DESIGN OF THE NEXT-GENERATION ATC TRAINING SYSTEM

EXECUTIVE REPORT

**Barbara Means, Randall Mumaw, Chris Roth,
Mark Schlager, Erik McWilliams, Ellen Gagne',
Virginia Rice, Doug Rosenthal and Susan Heon**

June 6, 1988

Sponsor:

**Federal Aviation Administration
OPM Work Order 342-036**

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EXECUTIVE SUMMARY

Our review of the FAA's current program for training air traffic controllers identified problems in four general areas:

- curriculum structure and sequence,
- integration of academic instruction with job skills,
- quantity and quality of skills practice, and
- provision of a complete cognitive model of how to execute control strategies.

In both the terminal and en route options, the current ATC training program is too much a piecemeal affair, with cases of illogical sequencing and unnecessary redundancies.

Although it is the stated policy of the FAA to provide job-context training, there are too many instances where the knowledge and basic skills needed by controllers are taught out of context, without any explanation of how they will be used on the job.

Students moved from academic training to simulator practice of ATC skills. However, simulator practice is insufficient in quantity and lacks a sound instructional focus. Simulators for facility training are expensive pieces of operational equipment, run by cumbersome software and deficient in instructional capabilities.

Recent advances in instructional psychology have resulted from using detailed analyses of task performance to guide training development. In contrast, ATC training tells students what result to achieve, without explicitly teaching the strategies for obtaining that result.

A set of 32 recommendations for improvements in the ATC training program are provided.

- Review each training curriculum in its entirety, developing a logical sequencing and removing decontextualized training. <
- Enforce the primary OJT instructor concept for the first half of each OJT phase.
- Develop software for systems to train keyboard entry, flight strip marking, and phraseology to automaticity. <
- Develop software for whole-task simulator/trainers for both manual and radar control. <

- Procure the equipment for an ATC Microcomputer Laboratory. Recommended quantities are eight workstations per center, four per TRACON, and two per tower hub facility.
- Fund development of an intelligent authoring aid for ATC training scenario development. <
- Conduct research on intelligent tutoring systems for air traffic control. <
- Sponsor several model CBI development projects.
- Specify instructional goals for simulation scenarios that integrate them with specific OJT training. <
- Provide part-time training assignments for 1-2 FPLs at each center.
- Invest in hardware and software development to permit use of personal computers for remote positions in the DYSIM lab.
- Review time and cost estimates for improving DYSIM and ETG software; initiate software improvements where practical.
- Decouple development of software for EST with that for ACCC and move up the EST implementation to follow introduction of the ISSS as closely as possible.
- Conduct cognitive task analyses of the development of the ability to visualize traffic.
- Remove the prohibition against teaching "technique" in ATC laboratories.
- Strengthen the OJT instructor's course to include demonstration and practice on how to give good diagnostic feedback.
- Develop a new curriculum to replace en route Phases V through VII, better integrating academics and practical experience.
- Reorganize the en route OJT curriculum with sequencing based upon sectors rather than positions.
- Replace the current en route Phase XI radar laboratory curriculum with an instructionally sound sequence of scenarios tied to the critical issues on specific sectors; provide for continued radar laboratory opportunities during OJT phases.
- Develop a more in-depth, centralized training program for terminals.
- Develop a well-structured, self-guided program for students entering lower-level terminals.

- Develop a medium-fidelity simulation for local and ground control positions.
- Develop interactive videodisc (IVD) training for teaching aircraft identification and operating characteristics.
- Conduct a cognitive task analysis for control using the ISSS, including an assessment of the effects of various configurations of system features.
- Conduct a thorough review of AAS contractor Training Plans.
- Initiate studies on various ACCC concepts to ascertain their effects on the controller's cognitive task.
- Conduct research on more cost-effective screening methods.
- Increase instructional design, computer science, and CBI development expertise on both the Academy and contractor sides of course development.
- Ensure that adequate job task analyses are performed prior to course development and that the analyses are used by course designers.
- Increase interaction between training developers and the field.
- Compare mechanisms for regulating training flow across regions and disseminate procedures used by the most successful regions.
- Elevate the status of training within the FAA by creating a Training Office at the Associate Administrator level.

In our judgment, implementation of these recommendations would reduce training time and produce more skilled controllers in a cost-effective manner.

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INTRODUCTION

Last year, as part of the Administrator's Impact '88 Initiatives, the Federal Aviation Administration (FAA) began a comprehensive review of its program for training air traffic controllers. One component of this review was an independent analysis undertaken by HumRRO International in the fall of 1987. HumRRO was asked to bring the perspectives of cognitive and instructional psychology to both an evaluation of the present training program and the formulation of recommendations for an improved program, the Next-Generation ATC Training System.

The products of this work are presented in the present report and in a companion volume, ATC Training Analysis Study Technical Report. This Executive Report describes the major findings of our evaluation and our recommendations for both near- and long-term changes in the way air traffic controllers are trained. The information and data used in formulating our recommendations are presented in the Technical Report.

Our assessment of the current ATC training system is based on visits to FAA facilities and discussions with air traffic controllers and other staff members at many levels of the administration. Although our exposure has been limited to a dozen air traffic control facilities, we are confident that the situations catalogued here are reflective of the entire system and not just a handful of sites.

A limitation of our report, which we are more than willing to acknowledge, is that it tells only one side of the story. It focuses strongly on the negative aspects of the present training system. The constraints of time and our goal of identifying areas where large improvements can be made led to this focus on training weaknesses. This uneven characterization is undeserved and requires a broad disclaimer. We talked to many individuals involved in the training program who have a sincere interest in improving the effectiveness of training. These people shared their ideas with us and contributed strongly to sections of this report.

We must acknowledge also that many of the weaknesses we observed in facility training stem largely from personnel shortages. The problems we document here are in many cases not the results of intent or policy, but stem from the shortage of experienced staff at many facilities. Our recommendations do not address this problem directly, but we believe that the implementation of many of our proposals would ease the burden on operational staff while producing more effective training.

EVALUATION OF ATC TRAINING

Our evaluation of the current ATC training program will be presented within the context of the four themes discussed in the last chapter: (1) training sequence and structure, (2) teaching academic knowledge and basic skills in a-job context, (3) providing ample practice opportunities with diagnostic feedback, and (4) teaching cognitive models of expertise.

Current Training Sequence and Structure

In both the terminal and en route options, the current ATC training program is too much a piecemeal affair, with cases of illogical sequencing and needless redundancies.

Early in their programs, students are typically given maps and a great deal of printed material to learn, with no principled sequence for learning it (and little or no guidance as to how to learn it). Academic material all tends to get shoved to the front end of facility training, regardless of when the student is going to use that knowledge. Hence, one finds students in terminals doing classroom work on eight different positions before starting OJT on any of them. One finds students in centers taking CBI related to radar control before they have even entered the nonradar lab. After spending 11 intense weeks at the Academy learning to control traffic in a nonradar environment, students do nothing with these skills for nearly a year (during which they are completing Phases V through VII). In what is perhaps the most striking example of illogical sequencing, the instruction in how to give on-the-job training is offered before radar-associate laboratories.

This lack of logic in the curricular sequence seems to reflect three debilitating factors:

- Although much attention has been given to trying to refine the ATC training system, most work groups and initiatives have looked at specific components of the program (e.g., CBI or OJT), trying to fix a small piece without being able to rework the whole.
- Design of the training system does not show the application of expertise from the fields of training design and the psychology of learning.
- Many different groups, inside and outside the FAA, are responsible for different parts of the training program.

During the course of our site visits, the negative effects of the last of these factors on the ATC training program were particularly marked. At centers, the CBI comes from the Academy; laboratories and classes are run by contract instructors; DYSIM software is the responsibility of the automation department; and OJT is provided by floor controllers (who question the expertise of the contract instructors). Terminals do not use contract

instructors but can have the same kind of schism between the Training Department and operational controllers.

Given this multiplicity of training providers, it is not surprising that in practice the sequencing of instruction tends to be driven more by instructional provider than by the content of the instruction. For example, at centers students typically are run through all the CBI for a phase before going to the lab, and all laboratory precedes going to the floor. In many cases, the CBI involves content that relates to something students won't see on the floor until months later; it is simply more convenient organizationally to check them off on all their CBI at one time rather than giving lessons when they are really needed. Similarly, Letters of Agreement are learned first as an academic exercise. Later, when students go to OJT, they have to re-learn the material. Similarly, at upper-level terminal facilities, students often go through academics and laboratory instruction with the Training Department for all positions and then get turned over to OJT instructors to be trained on all positions.

This fragmentation of responsibility leads to poor sequencing and disjointedness of training content ("Forget what they told you at the Academy...in class...in lab..."). Training providers get tunnel vision: They try to do the best they can with their little piece of the training program, but their goal becomes getting students through their particular part of training rather than working with other groups to lay the foundation for producing the best possible FPL.

An additional factor with a negative impact on the actual (as opposed to the Instructional Program Guide) curriculum sequence is the bottleneck created by the limited simulator facilities in the field. This problem will be discussed extensively below, but it is relevant here because many facilities end up shuffling the academic curriculum in order to give students waiting for simulator access something to do. We spoke with a number of students who had spent 18 months as Air Traffic Assistants ("strip rippers") in Phase VI. Some of these students had already had extensive A-side experience as ATAs or Co-op or Pre-Developmental students. Trying to provide some content during this period is sensible, but it should not be content that students are not ready to assimilate (i.e., Phase XI CBI) and that will only have to be repeated later on.

Academic Knowledge and Basic Skills

Although the stated policy of the FAA is to provide job-context training, in too many cases the knowledge and basic skills needed by controllers are taught out of context, without any explanation of how they will be used on the job.

A number of examples of this weakness in classroom instruction were observed by the project team and/or reported by students. For example,

- In an Academy class, strip marking procedures were taught without an explanation of how the way in which the strip is used on the

job makes some sequences of actions reasonable and others impossible.

- In a Phase VII class, students were given a lecture on the layers of the earth's atmosphere without any kind of air traffic control context; what, if any, value the information has for controllers was unspoken.
- In a refresher class, center FPLs were shown a videotape describing a new runway landing system.
- At a terminal facility, students were given numerous Letters of Agreement to learn without any demonstration of how controllers use LOA information.

Currently available CBI materials are replete with similar problems. The lessons feature little, if any, meaningful interaction. Students read screens of text and then take multiple-choice tests. The CBI lessons deal almost exclusively with factual knowledge, presented in a relatively linear and static manner, often without much explanation of the relative importance of the information or how it relates dynamically to other things that the student should already know. There are few situations in which the student is asked to apply the new information to ATC problems.

The present CBI courseware appears to follow a linear model which assumes that if the student first "learns" the facts (via CBI), those facts will be available when he or she needs them later in the laboratory or OJT. Unfortunately, learning does not often follow such a simple, linear model. In relatively complicated subject matter, the preference is an iterative, cyclical, contextual model, in which much of the actual insight occurs during the student's attempt to apply the new material to ATC situations. This model places greater importance upon the roles of context, application, and repeated opportunities for learning.

The results of all this are quite serious: Students entering centers and low-level terminals typically have very little idea about the details of air traffic control. They cannot be expected to see the relevance of the academic material for themselves, know what parts of the material are really important, or how to use the material on the job. Missing these essential parts of the puzzle, they can only "learn" the material through brute force memorization.

We often heard not only students but also instructors and controllers refer to academics as "memory work." Rote memorization is a very inefficient way to learn meaningful material. Although some memorization will be required for arbitrary material such as airport identifiers, much of the knowledge needed for air traffic control is conceptual. If students are taught the relevant concepts and how the material is used on the job, learning becomes a matter of understanding rather than memorizing.

A negative consequence of the fact that students do not see the relevance of much of what they are asked to learn is that they come to

regard early phases of training as "filling in a box." This creates cynicism about the training program (and the FAA) that can have long-lasting repercussions.

Finally, when academic and basic skills material is taught outside a job context, without a demonstration of how the information or skill will be used, it is less likely to be used when the student is actually on the job.

Practice and Meaningful Feedback

Simulator practice is insufficient in quantity and lacks a sound instructional focus; simulators for facility training are expensive pieces of operational equipment, run by cumbersome software and deficient in instructional capabilities.

The first point to be made with regard to practice is that the current ATC training system provides very little skills practice before OJT. En route developmentals receive approximately 65 hours on a DYSIM before being sent to radar OJT. At the TRACON facilities we visited, students get just 10-40 hours on the ETG before OJT. In the case of tower cab positions, there are no simulator facilities at all.

This approach to training is costly in several ways. First, FPLs are being used to provide 80 - 100% of the student's practical training. The current system places a large instructional burden on the operational controllers. Even FPLs who like to teach have grown weary of the constant training load. The goal should be to reduce the training burden on these people.

Second, not all FPLs are well suited to providing instruction. The role of trainer, which should be given only to those who understand how to do it well, is being handed to a very large group of people, many of whom consider it secondary or even a nuisance. This approach also greatly reduces any standardization that one might achieve in training. If the majority of training responsibility is retained by the training department, a better selected set of individuals can provide a better product.

Third, lives are at stake. It has to be remembered that the student, after very little preparation, is controlling live traffic. In one study of operational errors, 14% were found to have occurred during training. People do learn the most in situations where they have to "stretch" a bit to succeed. But there are serious questions about how much of this stretching we want ATC developmentals to do on the job. The use of inexperienced trainees to control traffic could become a public issue at any time.

In the Technical Report for this study, we describe two kinds of practice students need in order to acquire air traffic control skills: (1) extensive practice on the consistently mapped low-level skills and (2) more varied practice applying high-level skills within a whole-task (scenario) context. The importance of providing diagnostic feedback--explaining how the student can avoid problems in the future--was stressed as a requirement

for the latter type of practice. The current ATC training program could be improved in all of these areas.

Low-Level Skill Practice

To free cognitive resources for the most difficult parts of air traffic control (planning, decision making), low-level should be trained to automaticity--that is, overlearned to such point that they no longer require conscious attention. We found that students are not getting enough training on the low-level skills to achieve automaticity before moving to extensive whole-task practice on the simulator or even OJT. In our field work, we observed many laboratory and OJT sessions where the student had problems with data entry or phraseology. Since the simulator laboratories do not have a realistic simulation of the communications system, students get no practice on this until they reach the floor. Further, these skills are not tested for automaticity.

Scenario Practice

Providing realistic scenario practice is something to which the ATC training program has, quite rightly, given more attention. However, this portion of the program too is not nearly as strong as it might be. The first problem is lack of simulator facilities. The only simulators available use operational equipment, which is quite expensive and currently in short supply. This limits the number of simulators available at each facility. The supply problem is further exacerbated by the fact that the simulator software is device-intensive. One to four units are used for remote operators for each unit at which a student is trained. As a consequence, several million dollars' worth of hardware is typically used to train two students.

The costs in terms of human resource requirements are high as well. In addition to an instructor, one to four remotes are required, and often someone is needed to work another position (this may be another student receiving training, but on SET problems it is not fair to have two students working the same console). Figure 1 shows a typical DYSIM laboratory and the hardware and human resources needed to provide training scenarios for two students.

The effects on the en route training pipeline are quite serious. Figure 2 provides a graphic illustration of what happens to a class of 12 students entering a center. DYSIM becomes a bottleneck that chokes off training flow, creating a back-up in Phase VI A-side duties. (A similar back-up can occur as students wait for Radar Training Facility slots, but at least those students are meaningfully engaged in radar-associate training or operational duty.)

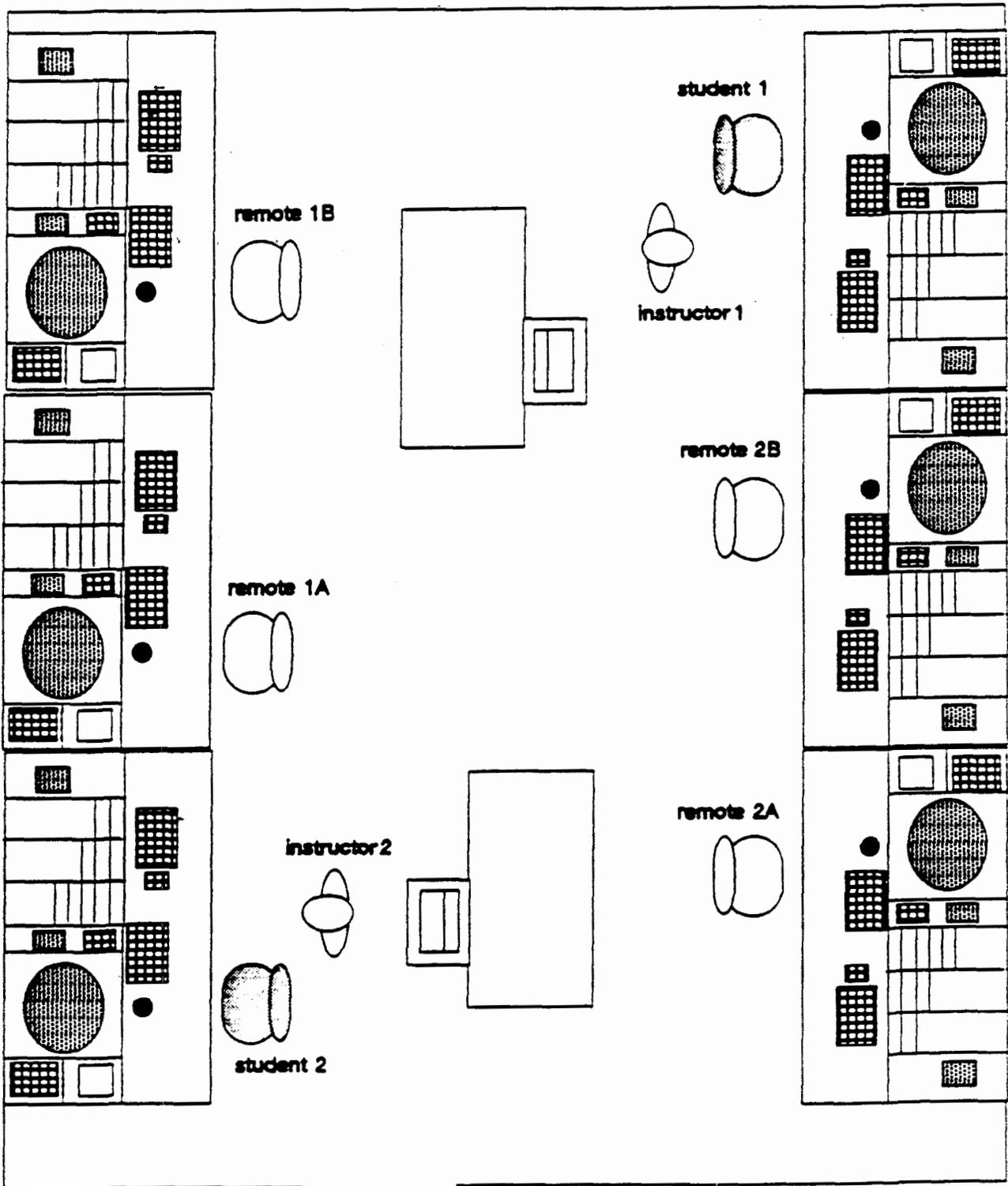
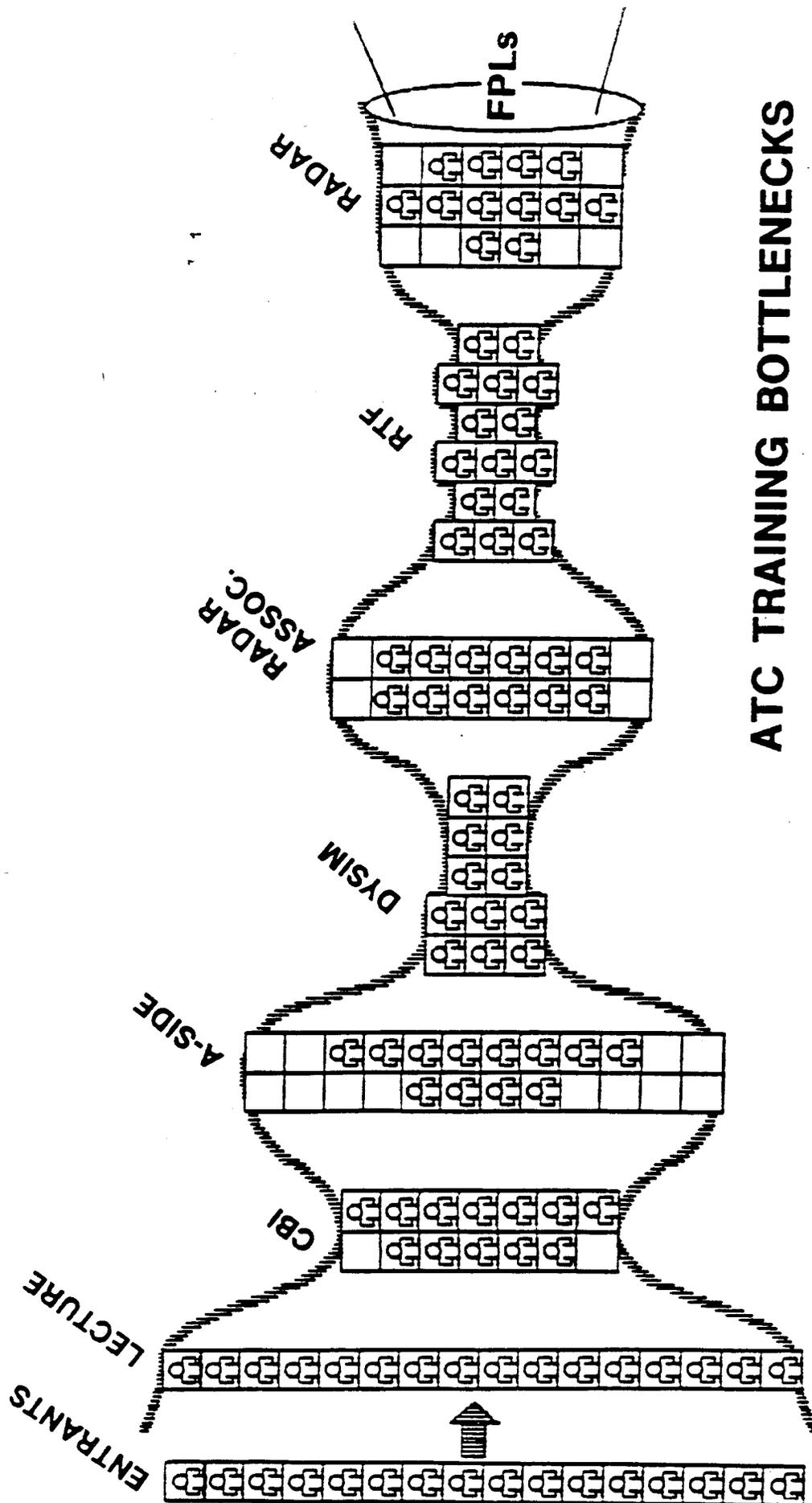


FIGURE 1. Typical DYSIM Laboratory Configuration



ATC TRAINING BOTTLENECKS

FIGURE 2

Other factors limit use of existing simulators as well. Largely because of the difficulty in getting the scenario tapes up and running and the extensive requirements for support personnel, simulator laboratories are not open evenings and weekends for extra practice.

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In addition to being limited in quantity, present simulator practice has several deficiencies in terms of quality. The DYSIM and ETG lack the desirable instructional features found in many current training systems. Their most serious weakness is the inability to replay a student scenario performance. Given the nature of the air traffic control task, it is frequently inappropriate to give feedback while a student is working a problem. Nevertheless, feedback is critical, and can be more detailed and clear if given as the student watches a replay of what he or she did. Neither the DYSIM nor the ETG has this critical feature. The ETG can freeze action, allowing the instructor to make points in mid-problem, but the DYSIM lacks even this capability. Neither system does any automated scoring of student performance.

In addition to these limitations on the simulators' capabilities, there are weaknesses in the content of the practice scenarios provided. Problems are most often criticized by floor controllers for their lack of currency. Changes that have been made on the floor are not necessarily reflected in the scenario content.

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We found additional weaknesses in the simulator problems from an instructional viewpoint. They do not reflect a sound instructional sequence. The order in which scenarios are presented is based solely on traffic complexity levels, and does not have a basis in an analysis of the skills or knowledge required to control traffic. The scenarios are not sequenced to facilitate the acquisition of skill in any programmatic way. The conceptual difficulty, as opposed to the traffic density, of successive scenarios does not necessarily increase, nor does practice on one scenario prepare a student for the next.

It is important to note that we talked with some scenario developers who brought great skill and instructional insights to their jobs. Unfortunately, their insights do not get shared across sites (or, sometimes, even transmitted to successors at the same site). The average person creating training scenarios merely tries to satisfy the IPG requirements and maintain traffic realism. Thus, the scenarios are not designed to teach specific skills, strategies, or proven ways of dealing with traffic problems in a particular sector.

Moreover, the difficulty level of the scenarios builds rapidly, with no provision for adapting to the individual student's learning rate. Scenarios quickly become so difficult that they are no longer a good context for learning new skills and strategies. This is not to say that students should not receive 100% problems during their simulator training, but simply that students should get many more problems at lower difficulty levels, with the problems focused upon particular instructional issues.

We see several causes for the deficiencies in the quality of simulator scenarios. First, the national program contributes to it by stipulating a limited set of simulator problems with rapidly increasing complexity levels (90% by the sixth problem and 100% by the 11th in radar training). Since the requirements for problems are stated in terms of complexity level and a few required features (e.g., an emergency procedure), these things are what scenario developers worry about.

Second, the scenario developers themselves typically have no background in the theory of instruction, consequently, it never occurs to many of them to use the scenarios as a medium for teaching specific skills. A related problem appears to be a carry-over of the viewpoint that the program is designed to screen out the inadequate rather than to train. If you are only trying to see whether an individual can separate traffic--as opposed to teaching him how to separate traffic--the present laboratory curriculum makes sense.

Finally, the development of more and better scenarios and the maintenance of scenario currency is hampered by the cumbersome, outmoded DYSIM/ETG software. Developing a new scenario should not take a week (the time estimate provided by several centers), and it should be easy for scenario developers to try out and refine new scenarios.

Feedback

DF The final issue with regard to practice of high-level skills is the need for meaningful feedback. This instructional principle gets lip service in ATC training, but in reality receives short shrift. In laboratory sessions it is common for a developmental to execute a scenario for an hour but to receive only a few minutes of commentary from the instructor. Further, that commentary is often quite skimpy in its detail and may be offered hours or even a day after the performance. Essentially, students receive too little feedback, it is often neither explicit nor complete, it may address only a few of the student's difficulties, and it may be presented so late that neither the developmental nor the instructor remembers many details.

The situation in OJT instruction is even less conducive to providing feedback. Typically, especially in later stages of OJT, developmentals may need to wait for long intervals before the traffic level is sufficiently high to test the developmental's limits. Such high traffic conditions often preclude much commentary by the OJT instructor during the session. Consequently, feedback is postponed until after the session, and its content relies on the ability of the instructor and the developmental to recall many details of the performance. Often, feedback is offered at the end of several sessions in the few minutes between leaving the floor and going home.

The roots of the problem in both laboratory and OJT sessions are similar: There is no record of the performance that could be used to guide

for comp. Application

feedback; there is often little time in the schedule for feedback; and feedback is often provided long after the fact.

Effects on Training Environment

Lack of ample practice opportunities for students prior to OJT produces a number of undesirable effects. In the first part of this section, we discussed the burden that lack of student practice places on OJT instructors and the difficulties inherent in trying to standardize a training program provided by thousands of FPLs who regard teaching as secondary to their jobs. In addition, the lack of adequate practice prior to OJT means that students start working with FPLs before they have learned everything they need to know about controlling traffic in their sector and often even before they have the mechanical skills down to a point where they can execute them without effort. As a result, FPLs can be harsh in their criticism of their students, and the credibility of the training department suffers.

Teaching Cognitive Models of Expertise

Recent advances in the psychology of instruction have come out of detailed cognitive analysis of how complex tasks are performed.

The difficult part of air traffic control occurs in the mind of the controller. Instruction will be more effective if these mental or "cognitive" steps are made explicit, i.e., if students are provided with models for how to mentally organize air traffic, set priorities, and select strategies for control. As psychologists, we tend to talk about "cognitive task analysis," but what we have in mind, although derived more formally, is not too far from what controllers call "technique."

The job of air traffic control cannot be done without using technique. The goal of the training program is to produce controllers with good techniques. Expecting students to come up with good techniques through unguided discovery is an inefficient approach for a training system. Although some students will discover good techniques, others will use marginal strategies. Rather than just telling students "Plan ahead" and "Separate traffic," trainers should demonstrate how to achieve these results and provide diagnostic feedback based on a comparison of the student's performance with a model of how the desired results can best be achieved.

Although technique certainly needs to get refined in practice with live traffic, the fundamentals of good controller technique should be taught on the simulator. In many cases, that does not happen. In fact, contractor trainers running the laboratories at centers report that they are not allowed to teach technique. This is left for OJT. Unfortunately, many OJT instructors report that (1) they don't think they should teach technique, (2) they don't know how to teach technique, or (3) they assume the developmental already has technique.

Several factors seem to underlie this state of affairs. One factor is fear that contractor trainers would teach poor or outdated techniques. A second is the notion that every controller has the right to his own technique and that explicitly teaching students how to do something would stifle their development, or force them to try to control traffic in a way that is not compatible with their unique abilities. Finally, there has been an effort to keep OJT instructors from underrating a student just because he or she does not use the same techniques as the instructor. Although these concerns reflect valid issues for ATC training, the response of not teaching technique ignores the fact that it is essential for air traffic control.

Given our belief that FPLs should be teaching the cognitive steps in air traffic control (both in OJT and in simulator scenarios), two related program deficiencies need to be addressed. First, the course for OJT instructors appears to be inadequate and is perceived quite negatively in the field. Although some of the attitudes and behaviors of OJT instructors have warranted the course's human relations thrust, the hardest part of being an instructor for a complex skill is learning to provide good diagnostic feedback. We saw some instructors who were superb in this area, but many were not. The OJT instructors' course needs to be longer and to include both demonstrations and practice in providing diagnostic feedback.

A related problem that we saw at several facilities was the practice of using large numbers of different OJT instructors for a developmental. (At one facility, the average number of OJT instructors students reported having was 14.) One of the most striking site differences encountered in our field work was the negative atmosphere in the training programs at these facilities compared to facilities where students have a primary OJT instructor. When students have to work with so many different OJT instructors, they have no single model of how to control traffic in their area. They frequently complain about getting graded down by one instructor for doing what their instructor the day before required.

Thus, the practice of using many OJT instructors prevents the student from receiving enough exposure to any one cognitive model to really acquire it. In addition, there are some more subtle decrements to the quality of OJT. It is quite likely that in many cases the students are wrong about different instructors having different rules for coping with the same situation--the two situations may not really have been the same. But if two different instructors were teaching on the two days, the second instructor cannot know exactly what happened the day before, and thus is in no position to explain how the situations were different. As a result, when many different instructors give a student OJT, training tends to be incomplete and disjointed, feedback is confusing, and no FPL has a good picture of the student's stage of development. There is, however, a value in exposing a student to several different instructors in the latter portion of his or her training. At this time, having mastered the set of techniques modeled by one instructor, the student is ready to consider alternative techniques.

The use of a large number of OJT instructors for a student's training also has a very real cost in terms of morale. None of the OJT instructors is likely to feel that he or she has a "stake" in the student's success.

Students suffer from lack of a mentor and feel "It's me against them." Admittedly, facilities are handicapped by staff shortages and scheduling contingencies, but the fact that other equally busy and understaffed facilities have been able to implement a primary instructor program argues that it can be done.

Conclusions

Our evaluation of the ATC training program suggests that major rethinking is required concerning the way air traffic control instruction is provided. Deficiencies have been identified in the curriculum structure; the degree to which academic and basic skills training is presented within a job context; the amount and quality of practice provided; and the presentation of a cognitive model for air traffic control.

We have focused on problem areas in ATC training because these are the issues on which action is required. We would not like to leave the impression, however, that there is nothing laudable about the current training system. With the important exception of neglect of cognitive models of expertise, the ATC training program is better than most in terms of matching content to job requirements. Moreover, a great many skilled, capable people are now providing training. Some of the facility laboratory and OJT instructors were particularly impressive. What we would like to see is a training system that better supports them, using their skills where most appropriate and providing organizational support and other types of expertise where needed. The next chapter presents our specific recommendations for actions directed toward this goal.

RECOMMENDATIONS

This chapter presents our recommendations to the FAA for improving the air traffic control training program. For each recommendation, we will provide a brief background statement followed by a proposed specific action. Recommendations are grouped to reflect first the four themes in our evaluation (Training Sequence and Structure, Contextualized Training, Ample Practice Opportunities, Cognitive Model of Expertise) and then related areas in which we believe improvements can be made (Option-Specific Curriculum Changes, AAS Training Plan, Screening, Training Materials Development, and Training Management). In the final section of this chapter, we will provide some cost estimates for our proposed changes and discuss those costs within a cost-benefit framework.

Well-Sequenced Training in a Job Context

Our evaluation led to the conclusion that the present ATC training curricula are neither well-structured nor sufficiently strong on presenting knowledge and basic skills in a job context. At this point, the programs have received many "patches," but the patches often serve to preserve the more global problems inherent in the curriculum design.

Recommendation: *Review each training curriculum in its entirety, developing a logical sequencing and removing training that is not in a job context.*

Two things need to be said about the required review. First, it should not be done on a piecemeal basis. Each option program needs to be reviewed from the top down, in its entirety. This is the only way to develop a coherent training sequence with a logical structure. Second, this review requires two kinds of expertise. One, naturally, is in air traffic control. It is essential to get the perspective of practitioners from the "front lines." The second type of expertise required is in instructional design and the psychology of skill acquisition. These latter domains are just as complex as air traffic control and are equally essential to building a sound training program. The two types of experts need to work together on a continuing basis and on an equal footing.

Recommendation: *Enforce the primary OJT instructor concept for the first half of each OJT phase.*

For students to acquire a cognitive model of expertise (or a set of good techniques), they need repeated exposure to the model along with practice and feedback. It is difficult to acquire any model when you are faced with different ways of doing things each day. This argues for giving a student an extended period with one primary instructor.

At the same time the instructor, to be a good diagnostician, to have a good idea whether the student is just a bit slow this morning or has a real problem with estimation factors, must have extended exposure to the student. It is difficult to judge a student's progress, and particularly difficult to

assess his or her readiness for check out, if the instructor only sees the student once in a while.

Both of these needs argue for use of a primary instructor. In addition, our observations lead us to believe that the primary instructor approach leads to a much more humane training program. We would note, however, that the current practices of having a different instructor on the OJT's day off, of permitting a change in instructors in cases of mismatches, and of using a greater variety of instructors toward the end of the training phase are all appropriate.

Ample Practice With Meaningful Feedback

ATC training can be improved tremendously by providing more practice--and more carefully designed practice--in the time allotted to training. Our evaluation revealed many factors restricting the amount of skills practice available: Notably, the lack of meaningful interactions in the present CBI materials and dependence upon a limited number of highly expensive simulators that require large amounts of personnel and hardware to provide a single student with simulator training.

One effective solution to the need for more practice opportunities on both low-level skills requiring automaticity training and high-level skills requiring whole-task training would be the development of a series of automated trainers capable of running on less-expensive equipment than the current DYSIM and ETG (or the planned DCT). The latter are highly expensive pieces of equipment which should be reserved for advanced training, immediately preceding and concurrent with OJT.

Recommendation: *Develop software for systems to train keyboard entry, flight strip marking, and phraseology to automaticity.*

We recommend moving training of low-level skills out of the high-cost, high-fidelity simulator and live traffic situations. By training these skills to automaticity on lower-cost, more accessible training systems, the FAA can reserve the high-fidelity simulators for providing whole-task training with high realism prior to OJT. If a student is to really get the most improvement in these areas out of his time on a high-fidelity trainer, he needs to have the low-level skills automatized so that they are not taking up limited mental resources required for higher-level skills such as planning and decision making.

Recommendation: *Develop software for whole-task simulator/trainers for both manual and radar control.*

Inexpensive mock-ups and low-fidelity simulations can be used to provide the hundreds of practice trials needed to obtain automaticity on skills such as keyboard entry and communications procedures. We have argued, however, that early training should not consist solely of practice on low-level supporting skills. Whole-task training, provided on a medium-fidelity simulator, can give the student practice in integrating skills and

knowledge within the context of air traffic control scenarios. This should enhance not only skill acquisition but also the attainment of automaticity. In addition, a lower-cost system capable of presenting ATC scenarios would make it possible for students to get much more skills practice than they obtain now, simply because of the greater availability of the simulator/trainer. Finally, in developing such a system, the FAA can make sure that the many desirable instructional features missing from DYSIM and ETG (e.g., playback, automated scoring) are built in.

Recommendation: *Procure the equipment listed in Table 1 for use in an ATC Microcomputer Laboratory. Recommended quantities are eight workstations per center, four per TRACON, and two per tower hub facility.*

The training systems recommended above should be designed to run on reasonably low-priced off-the-shelf computer hardware. In thinking about the kinds of hardware that would best serve ATC training needs, we were strongly influenced by concern with providing enough workstations so that students would have ample practice opportunities. Any workstation that is highly expensive is going to be limited in supply. Given the amount of practice needed in many task components, there is virtue in simulator numbers.

A second consideration was the need for flexibility in the training system. ATC training needs will change, not only as the AAS is introduced, but also as staffing patterns and the prior experience levels of developmentals change. By obtaining hardware systems with as much flexibility as possible, the FAA can avoid getting stuck with equipment that receives little or no use in the future.

Given these considerations, plus recent advances in the power and capabilities of microcomputers, we are recommending the procurement of a microcomputer workstation capable of running all of the training software described above.

The workstation is built around a central student monitor with a very-high-resolution (VHR) color graphics controller (1280 by 1024 pixels) for presentation of simulated radar screens. Two additional monitors are included for multiple, coordinated displays. At times, the student might view a radar simulation on the central monitor while getting flight strip information or CBI on one of the other monitors. The alternate monitors could also be used by an instructor, by remote operators, or by other students in team training.

For centers and TRACONS, the workstation also includes a computer-controlled mechanical mock-up of the controller's operator console with a trackball. This mock-up can be used in training keyboard skills to automaticity. (Note that a new mechanical mock-up will be required for the ISSS.) Similarly, a simulated communication system is recommended. A low-fidelity simulation of the operator's console, using a touch-sensitive plasma panel display, is recommended for use by the instructor or a remote or by students in portions of their training where lower physical fidelity is adequate. (An advantage of this latter piece of hardware is that the

console simulation can be changed so that the panel display hardware would not have to be replaced after introduction of the ISSS.)

The workstation for tower hubs would not include the mechanical mock-up of the operator's console but would include a videodisc player.

The specific components of this workstation are listed in Table 1, and Figure 3 provides a graphic illustration of the set-up. Many of these components are identical or similar to components in the AATS equipment specified in the Office Automation Technology and Services (OATS) Request for Proposals. A comparison between this recommended hardware and OATS hardware is provided in Table 2.

Recommendation: *Fund development of an intelligent authoring aid for ATC training scenario development.*

Effective use of the simulation system developed for the ATC Microcomputer Laboratory will depend upon the facilities' capabilities to develop site-specific, instructionally sound scenarios. In the Technical Report, we described what we regard as deficiencies in the current scenarios and in the process whereby they are developed. Essentially, we have argued for the development of much larger numbers of practice scenarios, including many at lower levels of traffic density. If students are to acquire principles and concepts from their experience in working scenarios, the scenarios must be at a low enough level that the student can "stay ahead" of the traffic.

In addition, scenario developers should have specific instructional goals or objectives in mind and should have worked out a logical sequencing of these objectives. At present, personnel developing training scenarios generally don't have any background in instructional design, and only a minority have given consideration to instructional goals and sequencing on their own initiative. A further hindrance to the development of adequate numbers of instructionally useful scenarios is the fact that scenario development is such a labor-intensive practice with the current software--a week's worth of labor or more to produce a single DYSIM scenario.

Both of these needs can be addressed by developing an automated aid for scenario generation. The system could be developed for the workstation described above, and could be used to construct scenarios both for the simulation running on that hardware and for the DYSIM or ETG. (The scenario can be constructed, tried out, and refined on the microcomputer, and then converted into the format required for input into the DYSIM or ETG.) With more user-friendly software, it should be possible to build and refine a scenario in half a day, according to the experiences reported at the FAA Academy and elsewhere.

TABLE 1

ATC MICROCOMPUTER LABORATORY

COMPUTER

20 MHZ microcomputer with 2MB RAM, 40 MB hard drive, 1.2 MB floppy drive, floating point co-processor, digital audio output system, dynamic voice recognition system, interterminal voice communication system and headsets, high-resolution color graphics controller, serial and parallel ports

MONITORS

Two very high-resolution color graphics monitors (1280 by 1024 pixels) plus one medium resolution color graphics monitor (640 by 480 pixels), all touch-sensitive screens

ATC PRACTICE AND TRAINING CONFIGURATION

- Stand-alone, with voice recognition of communication to simulated pilots and controllers
- Network for instructor-monitoring and coordinated training with interterminal voice communication
- Medium-fidelity touch-sensitive plasma panel console or high-fidelity, mechanical simulation
- High resolution color graphics for simulating PVD
- Simulated flight strips via video display or use of flight strip bay
- Dot matrix printer for flight strips, grade sheets, and screen prints

CBI LESSON CONFIGURATION

- Trackball and touch-sensitive CRT screen
- High resolution color graphics and videodisc display
- Touch-sensitive, dynamically reconfigurable operator's console
- Dot matrix printer for grade sheets and screen prints

FIGURE 3

Student and Remote Stations for Stand-Alone or Coordinated Training in the ATC Microcomputer Laboratory

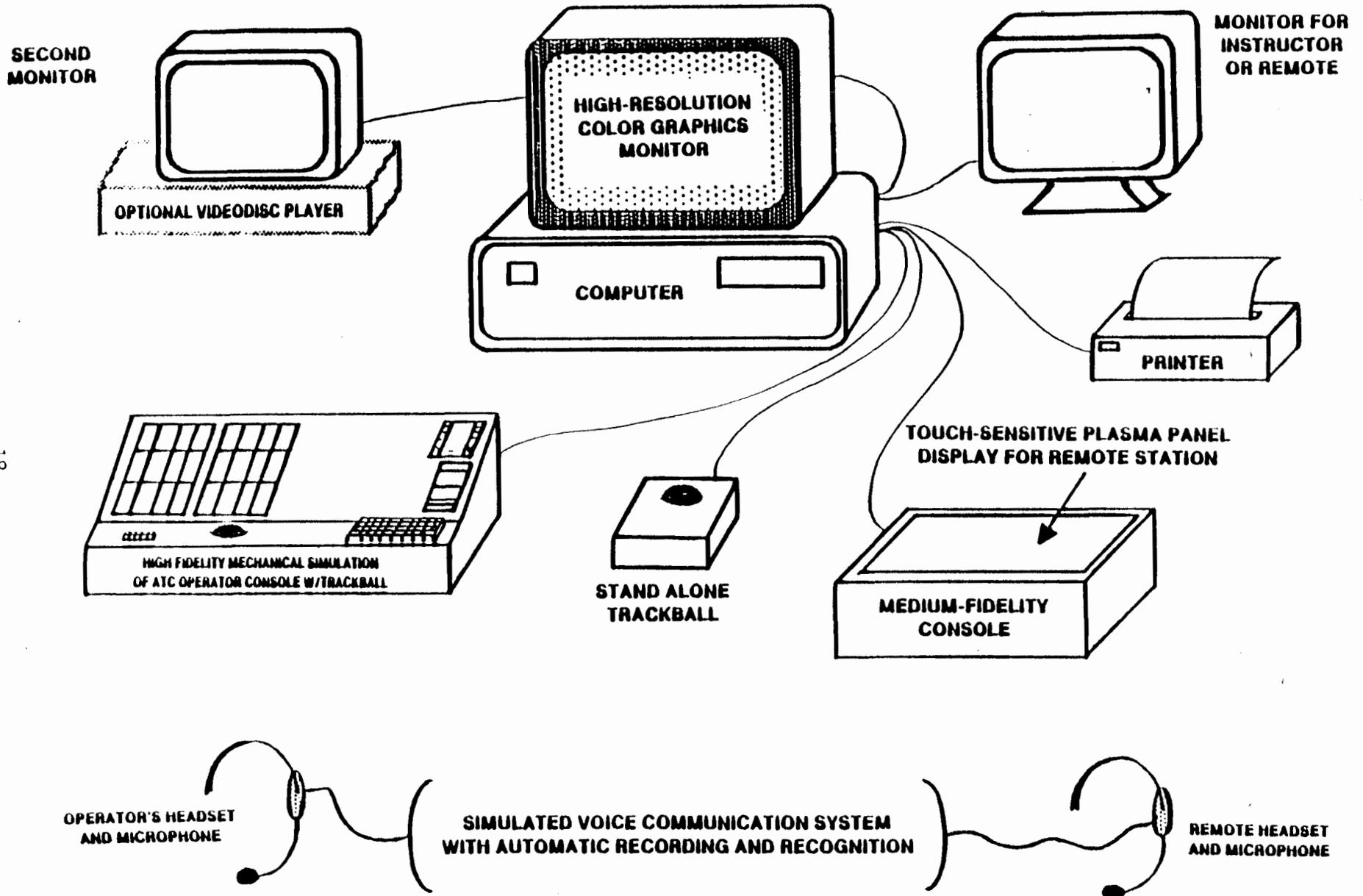


TABLE 2

Comparison of Hardware Recommended for ATC Microcomputer
Laboratory with Hardware Specified for OATS/CBI

- I. *Items in the OATS/CBI RFP Judged Adequate for ATC Microcomputer Laboratory*
 - A. R2 Workstation
 - 32-Bit Processor and Data Path
 - Up to 8 MB RAM and Plenty of Disk Storage
 - Posix Environment and Operating System
 - Hardware Interrupts and Software Service
 - Lockout from Accidental Re-booting of Operating System
 - B. WS-1 Configuration
 - R2 Workstation
 - 2 MB RAM
 - Dot Matrix Graphics Printer
 - One Medium Resolution (MR) Color Monitor (at least 640 by 480 pixels)
 - Touch Screen
 - Track Ball (1)
 - Digital Audio Recording and Playback System
 - Power Conditioner
 - Full CBI Authoring and Delivery Software
 - Operating System and Editing Software
 - Videodisc
 - Ability to Superimpose Video and Computer Graphics Displays
- II. *Items Recommended for Training via Simulation but Missing from OATS/CBI RFP*
 - A. Very High Resolution (VHR) Graphics Controller (1280 by 1024 Pixels) VHR Monitors for Multiple, Coordinated Displays
 - B. Computer-Controlled Mechanical Device for Simulation of ATC Console
 - C. Touch-Sensitive Plasma Panel Operator's Console
 - D. Small Flight Strip Bay
 - E. Speech Recognition Hardware and Software for Phraseology and for Training in ATC Without Requiring Other Operators as Remotes
 - F. Up to 4 Serial Ports on the Processor, for Coordinated Training
 - G. Multiple Trackballs and Operator Consoles for Coordinated Training Involving Student and Instructor or Remote on the Same Simulation
 - H. Floating-Point Co-Processor for Fast Computation

In addition, we urge the FAA to consider the advantages to be gained from building some instructional design knowledge into the scenario development software. Such a system could bring instructional issues to the developer's attention, solicit instructionally relevant information regarding each scenario, and employ instructionally sound default values for sequencing, difficulty levels, etc.

Recommendation: *Conduct research on intelligent tutoring systems for air traffic control.*

After surveying the present state of ATC training, we concluded that microcomputer-based simulator/trainers that provide an operationally realistic environment for practicing scenarios could bring vast improvements to the present training system. Placing great value on getting improved systems into the field facilities as quickly as possible, we limited our recommendations above to systems high on training utility but low on AI techniques. Although more advanced, intelligent tutoring systems have been developed, such a system has yet to be put into operational use for training a task comparable to air traffic control.

Nevertheless, we feel that the potential payoff of intelligent tutoring systems for ATC training is large. Moreover, the first step in developing such tutoring systems is the performance of an extended cognitive task analysis. This activity itself would contribute to the design of more traditional training even if subsequent development of a tutor were not pursued.

Recommendation: *Sponsor several model CBI development projects.*

The current training program could be much improved if, in addition to the simulator/trainers described above, "mini-simulations" and interactivity were incorporated into the CBI lessons. The FAA's training developers now regard these lessons as "academics" and basically provide text on a screen with interaction limited largely to taking multiple-choice tests. This is poor CBI design and is inappropriate to much of the training content. Good CBI is more expensive to produce, but the price difference is not that great. Our impression is that those doing development work are relatively inexperienced as CBI developers and often do not have models of what good CBI for air traffic control would look like.

We recommend that the FAA first review existing CBI for some important content areas that are poorly handled and then fund several "model CBI development" projects. This would give the agency a chance to work with some additional contractors, and there are many firms turning out excellent materials. The FAA would not only gain valuable products, but would also then have a set of models that demonstrate how to use more effective instructional techniques within CBI.

Recommendation: *Specify instructional goals for simulation scenarios that integrate them with specific OJT training.*

We would like to see better integration between laboratory training and OJT. Part of this integration involves specifying what students need to know to control traffic in a particular area and then developing simulator scenarios to stress those principles. Another aspect concerns allowing students to move back and forth between on-the-job training and simulator training, as appropriate. If the scenarios really do address the skills and knowledge needed on the floor, it will be natural to provide additional practice on specific areas where the student has demonstrated a weakness on the floor. This offers a large advantage for situations that give the student trouble but occur too infrequently within his or her sector to provide adequate practice.

Recommendation: *Provide part-time training assignments for 1-2 FPLs at each center.*

The meaningful integration of simulator practice and OJT requires the participation of FPLs in designing and administering scenarios. Upper-level terminals already use FPLs on rotational training assignments, but centers normally do not. (Labs are run by contractor instructors.) FPL involvement would help identify useful techniques for dealing with each sector's "traps," facilitate maintaining scenario currency, and provide students with an FPL "role model" at an earlier point in training. The Seattle CERT program has been run by FPLs, and we believe this factor has contributed to its success.

We should make it clear that we are not recommending wholesale replacement of the contractor trainers with FAA employees at this time. It is our impression that centers do not have the FPL staffing to permit current controllers to assume all of these functions. Moreover, there is a value in having more permanent training staff members: They gain extensive training experience, know the program, and can handle time-consuming administration and documentation requirements.

Recommendation: *Invest in hardware and software development to permit use of personal computers for remote positions in the DYSIM lab.*

We envision the proposed ATC Microcomputer Laboratory as a training resource to be used prior to working on the high-fidelity simulator (DYSIM or ETG). It will take some of the training burden off of those systems since students should be much better prepared upon entry to the ETG or DYSIM laboratory. Under these conditions, the present DYSIM and ETG programs would be more appropriate for a final check-out before starting OJT since students would have had the opportunity to acquire the skills on which they were being assessed.

Nevertheless, given the number of students being trained at centers, DYSIM units will continue to remain in short supply. The easiest way to gain some leverage in addressing this supply problem appears to be to use personal computers, rather than DYSIM units, for remote positions. Since

the Technical Center is already doing this, its technical feasibility is established. Since as many as four remote positions are now used to support one student, this innovation would increase dramatically the effective DYSIM supply for training.

Recommendation: *Review time and cost estimates for improving DYSIM and ETG software; initiate software improvements where practical.*

We identified a number of areas in which the DYSIM and ETG software could be improved, either to promote greater operational realism or to add desirable training features. Areas that need improved realism include call signs, aircraft operating characteristics, airport departures, and the communication system. Desired training features include freeze (for the DYSIM), back-up and replay, and automated scoring. Each of these improvements would have a price in software development, and the simulator software is written in a computer language that is now rarely used.

Provisionally, we are recommending that these improvements be made, but it would be prudent to ask the Technical Center for time and price estimates on each before making a final decision. Given the nature of the DYSIM operating system, the back-up and replay feature would probably be unacceptable in terms of expense. The timing for introduction of the EST software vis-a-vis the date when these DYSIM/ETG improvements could be implemented is a second decision factor.

Recommendation: *Decouple development of software for EST with that for ACCC and move up the EST implementation to follow introduction of the ISSS as closely as possible.*

Many of the limitations of the DYSIM and ETG, in terms of lack of training features and of requiring full units for remote positions, are to be corrected with the EST software. Unfortunately, we were told that development of the EST software is being deferred until the ACCC operational software is completed. Once again, the plan is to embed the training software into the operational software. This is a surprising decision considering the problems caused by developing the DYSIM software this way. Further, the delay in introducing the EST software, until 1997, means that in the meantime DYSIM software will have to be used to train students on the ISSS common console. It is our view that the EST software should be developed separately from that for ACCC to enable development to begin as soon as possible and to prevent the kinds of problems that occurred with DYSIM software.

Provision of Cognitive Models of Expertise

Air traffic control is a complex task that challenges human abilities to organize large amounts of information and respond quickly in a dynamic environment. The critical components of control--recognizing meaningful patterns in the traffic, planning, and selecting strategies--occur in the controller's mind, not in physical actions. These task components, what we have called a cognitive model of expertise, are not consistently taught in

ATC training. Students are told to "See the traffic" and "Plan ahead," but are not told how to do it.

Recommendation: *Conduct cognitive task analyses of the development of the ability to visualize traffic.*

As part of this project, we conducted some of the preliminary data collection and analysis for a cognitive task analysis of expert controllers. From this work, it is clear that experienced controllers selectively attend to portions of the jumble of information available to them and mentally organize air traffic. Specifically, they organize traffic not in terms of the representation on the radar screen, but rather in terms of categories related to potential control problems and strategies.

Given the importance of training developmentals to "see the traffic," we believe it would be worthwhile to conduct further work in this area, extending the data collection both to less-experienced controllers (e.g., new FPLs) and to developmentals. Often, it is through contrasting expert performance with that of the novice that the cognitive psychologist can most clearly identify the components of expertise. Further, such work can identify ineffective forms of mental representation used by novices and may suggest the course of development over time. These analyses could then be used in designing appropriate instructional interventions. Studies should be conducted in both radar and nonradar environments.

Recommendation: *Remove the prohibition against teaching "technique" in ATC laboratories.*

We are strongly convinced that students need to be told not just what result to achieve (i.e., keep traffic separated) but also how to achieve that result in specific circumstances. Students will get more out of laboratory practice if they have the opportunity to observe expert strategies for dealing with various types of situations and if a cognitive model of expert performance is used as a basis for diagnosis (i.e., the student is told not just that he exercised poor speed control but is shown the information and technique the expert would use to do it well). Some of this goes on in laboratories already, but officially the contractor trainers in DYSIM are prohibited from supplying this kind of feedback, which is regarded as "technique." The student must develop some technique, and it is more efficient to provide him or her with good models than to leave the discovery process to chance. An expanded role for FPL controllers in center laboratories (recommended above) would facilitate the provision of cognitive models of expert performance and of meaningful diagnostic feedback.

Recommendation: *Strengthen the OJT instructor's course to include demonstration and practice on how to give good diagnostic feedback.*

The few days that controllers spend in the present OJT instructor's course are not regarded as worthwhile by most FPLs. The course focuses on human relations issues and on paperwork. While both of these are important, there is much more to becoming a good OJT instructor. The essential skills

are (1) being able to provide a good cognitive model of how to do the task, and (2) being able to provide diagnostic feedback.

These skills depend upon the instructor's ability to reflect upon how he does what he does, to articulate his strategy, and to break procedures down in a way that allows the student to assimilate them. This can be very difficult for an experienced performer for whom the whole task has become so automatic that it seems like second nature. Being a good diagnostician can be even more difficult. The expert instructor doesn't just apprehend that the student did poorly, he figures out why the student got into trouble--that is, the missing piece of knowledge, incorrect assumption, or faulty step in a procedure that led to an unsatisfactory outcome. These instructional skills can be acquired, but they take time to learn and themselves require coached practice with feedback. The OJT instructor's course needs this kind of content.

En Route Training Program

In addition to the program-wide recommendations above, we have a number of more specific recommendations regarding training of ARTCC developmentals.

Recommendation: *Develop a new curriculum to replace Phases V through VII, better integrating academics and practical experience.*

The current Phases V, VI, and VII are designed to familiarize a student with his area of specialization, teach him the A-side duties, and prepare him for learning the radar-associated/nonradar position. Training during this period has become highly fragmented, with little sense that the various curriculum elements complement and build upon each other. Moreover, there is considerable unstructured and "dead" time, and much of the traffic visualization skill that a student developed at the Academy is allowed to decay for lack of practice.

We recommend that a more structured training program be developed to replace the current system. In principle, this new introductory phase retains the same goals. However, we believe that it can be better accomplished in less time (probably 4 to 5 months), given a set of structured activities. These activities would be oriented toward learning one's area and learning the mechanical skills required for radar-associated/nonradar control.

Initially, some position monitoring could be used to improve the student's understanding of the key concepts of the job. The student should understand the goals of training and the purposes for learning the material presented by lecture and CBI. Next, there is the need to learn the airspace. The traditional self-study of maps should be enhanced with some innovation. Current training technologies--sophisticated computer trainers and interactive videodisc--could be harnessed to address this particular need. Practice in relating two-dimensional radar presentations (shown on a CRT) to a three-dimensional representation (shown on videodisc) could be alternated with service on the A-side. Other training aids--such as CBI and

mechanical mock-ups--can be available to the student to be used when time permits. A classroom section should be available at regular intervals for presenting academic material, answering questions, and tying learning together in a job context.

Recommendation: *Reorganize the OJT curriculum with sequencing based upon sectors rather than positions.*

The radar associate and radar positions involve different operations, but both require detailed, well-integrated knowledge of the sector and its traffic patterns. Our work with experienced controllers at Jacksonville ARTCC convinced us that this sector knowledge plays a critical role in air traffic control. We recommend that the OJT curriculum be organized around sectors rather than positions (R-side or D-side). That is, students should receive radar associate OJT on a sector until it is mastered and then move to radar training on the same sector. After mastering both positions on a sector, the student would move to a new sector, repeating the radar associate/radar position sequence. (The site-specific plan implemented at Chicago uses this sector-based organization after the first two sectors are learned for each position.)

After a student has learned a sector thoroughly from the radar associate position, he has acquired a great deal of knowledge about the airspace. This knowledge can facilitate radar training for that sector if the knowledge is sufficiently recent and therefore still readily accessible in the student's mind. The difficulties and traps presented to the radar controller on a sector will be strongly related to those faced by the radar associate on the same sector.

An important principle in instruction is to teach new operations within a familiar content. The well-known sector is familiar content that provides a context conducive to learning radar operations. One cautionary note, based on Chicago's experience, is that students need more radar associate time on their initial pair of sectors if they are going to go directly to radar training (rather than waiting to complete radar associate training on all sectors).

Recommendation: *Replace the current Phase XI radar laboratory curriculum with an instructionally sound sequence of scenarios tied to the critical issues on specific sectors; provide for continued radar laboratory opportunities during OJT phases.*

At Seattle Center we observed their Computer Enhanced Radar Training (CERT) program. The program was developed because the FPLs and FAA training staff at Seattle Center were dissatisfied with the effectiveness of the radar training laboratory (Phase XI). One source of this dissatisfaction was the strict set of requirements for scenario development (i.e., traffic density, events, etc.) imposed by the IPG. More generally, the radar laboratory was seen as inadequate. They felt that laboratory training addressed basic radar skills, and assessed aptitude for more advanced training but left critical radar training for OJT. Their goal was to accomplish as much of the realistic OJT as possible in a simulated

environment to remove much of the training burden from OJT instructors and provide more effective training in a safer training environment. By pooling the efforts of FPLs from each area, laboratory problems were developed to begin teaching what the FPLs felt were the critical lessons to be learned in each area. The resulting Computer-Enhanced Radar Training (CERT) program is given after Phase XI and counted as OJT.

OJT time has been dramatically reduced on initial sectors for students completing the CERT program (by 50%). Also, by moving the training from the floor to the lab, the number of instructors is reduced, which allows greater standardization of instruction. The instructor can concentrate on training exclusively, without worrying about operational errors and safety.

Another important aspect of the CERT program is the strong emphasis on sector-specific training. Students are told about the traps and typical patterns of the sector they are going to work. This is learned in a realistic simulated environment. The students appreciate the realism in both the traffic situations and the control procedures. Most important is that this training helps students understand that sector's airspace and the functional characteristics of the traffic in it. This type of knowledge seems to be critical for competent performance.

Terminal Training Program

In becoming familiar with ATC training, we quickly perceived that low-level terminals are the poor stepchildren of air traffic control. Receiving inputs straight from the Academy, they serve as the "farm team" for upper-level terminals and yet typically have no resources for training.

Recommendation: *Develop a more in-depth, centralized training program for terminals.*

Currently, the FAA Academy provides a 4-week terminal training course for students assigned to the terminal option. This course immediately follows the Academy Screen. Classroom work is used to present the basic information, procedures, and equipment with which students must be familiar. A tower cab mock-up roughly simulates situations typically encountered on the job. The Terminal Follow-on was developed because low-level terminal facilities, where the majority of terminal-option Academy graduates are sent, have no training staff or CBI resources for teaching the basics of air traffic controller duties. Further, there is a trend in recent years that students coming into the FAA have little or no aviation background.

The reports that we received in the field indicate that the Terminal Follow-on program is reducing the amount of training that must be done at each terminal, but many feel that more centralized training is needed. On several occasions we were told that the Terminal Follow-on does not provide sufficient depth. Our observations support this. The addition of tower cab simulator facilities at the Academy will help, but problems will remain because of the adverse effects of the Screen on student motivation levels. After completing the Screen, students have little motivation to work

seriously in a training capacity. Indeed, even the short terminal program now being used is compromised because of the motivation problem. There will still be basic training required that cannot be supported by the resources available at low-level terminal facilities. We believe that a more in-depth, centralized training program could address much, although probably never all, of the terminal training.

We recommend that a national work group, representing Level I-III terminals, be convened to formulate recommendations for a more in-depth centralized terminal program. This program could be offered at the Academy, at hub facilities, or at regional offices.

Recommendation: *Develop a well-structured, self-guided program for students entering low-level terminals.*

As we have described, the biggest problem for training in the low-level terminal facilities is that no resources (human or technical) are available for training. Typically, students are placed in a room with a stack of documents and asked to develop their own training program (i.e., "Here, learn this."). Facility FPLs and staff assist when the student comes to them with a question, but under these circumstances, even the formation of a good question is often difficult.

Provision of a well-structured self-study program is highly desirable. This program could be presented by CBI or other automated systems if they are made available to each facility, or it could simply exist on paper. The critical elements are a structured program for organizing learning. The organizational structure could be developed at the national level; it should be informed both by an analysis of terminal operational requirements and principles of instructional sequencing. Facilities would then be responsible for inserting facility-specific information into the program's structure.

Automation of this program would make it easier to keep the facility-specific information up-to-date. For many facilities, this alone would provide a benefit since updating is often difficult and, therefore, often neglected.

We suggest organizing the content around the operational positions. Students could precede OJT on each position with the program of learning for that position. It is unlikely that the development of this program would make all facility instruction (presented by a human) unnecessary for new students. However, if this program were combined with a more in-depth, centralized training curriculum, the need for FPLs to do classroom training could be greatly reduced.

Recommendation: *Develop a medium-fidelity simulation for local and ground control positions.*

Low- and mid-level terminals carry the burden of training entrants into the terminal option yet have no training resources for fulfilling their mission. During our site visits, we spoke to managers, supervisors, and

FPLs concerning areas where more training is needed and might be offered via microcomputer-based training devices. One priority area from their standpoint is teaching local and ground controllers skills for setting priorities and making decisions.

Problems in sequencing aircraft and assigning priorities to aircraft can be effectively taught with a medium-fidelity simulation. Several tower cab controllers described difficult problems in sequencing pattern traffic, sequencing arrivals, and sequencing departures that students--and FPLs of all skill levels--rarely get to practice in the real world. We believe that sequencing problems could be effectively simulated with a videodisc player and a microcomputer support and interface.

Instruction on the visual aspects of tower cab positions could be done with a 180-degree videodisc application. (In most instances, an individual controller is only responsible for 180--not 360--degrees. Regardless, the concepts could be learned and practiced in this way.) Generic or site-specific training could be developed using actual video images from the tower perspective showing runways and geographic landmarks. These could be overlaid with computer-generated aircraft to simulate take-offs and landings of aircraft typical for the facility. Audio could simulate pilot-controller communication.

Recommendation: *Develop interactive videodisc (IVD) training for teaching aircraft identification and operating characteristics.*

Currently, students must learn aircraft identification, an important component of terminal control, from a book of black and white pictures. This is not well structured and provides no guided instruction. Knowledge of aircraft characteristics, such as climb rate, is also critical to good control. Again, this knowledge is picked up on the job as time and opportunity permit. Videodisc capability has been used for training in other aviation-related applications, and could easily accommodate controller training of this type.

In training aircraft identification skills, for example, an IVD-based system could present aircraft at multiple angles, in motion, and under various light and weather conditions against a backdrop of the view of the local airport runways from the tower cab. Also aircraft can be paired to distinctive features that remove confusions. To teach functional characteristics, the program might require students to group aircraft by climb rate or other performance characteristics.

This training system could be used separately or in combination with the local/ground control simulation so that the identification component is embedded in the simulation training as an aircraft "library." For example, a student could be given an arrival sequencing problem that includes an aircraft with which he is unfamiliar. The student could freeze the sequencing problem and call up the aircraft library to determine the typical airspeed of the aircraft. At this point, he would return to the sequencing problem and apply the knowledge just learned. This application places learning in the job context and makes it more effective.

If IVD training materials are developed, they should be designed within the context of an overall training plan. We envision IVD technology implemented in conjunction with CBI and medium-fidelity simulation training curricula at the centralized facilities (hubs, Academy) mentioned above as possible sites for terminal training.

Advanced Automation System (AAS)

We reviewed plans for the AAS to make sure that our training recommendations would be compatible with introduction of the new systems. That review raised concerns over how little is known about how controllers will work with the new hardware and software. This kind of understanding is needed not only for projecting training requirements but also for the design of good systems and operational standards.

Recommendation: *Conduct a cognitive task analysis for control using the ISSS, including an assessment of the effects of various configurations of system features.*

In reviewing man machine interface (MMI) testing for the AAS, we were surprised to learn that so little has been done to analyze how the ISSS (and later the ACCC) will change the cognitive task of air traffic control. The flexibility of the new common consoles in terms of information display and available interaction devices is very high. While this is good from a system design standpoint, it makes it incumbent on the FAA to do the necessary research to distinguish between good and poor ways to use the available system features.

Issues of potential information overload are a real concern. The best way to address these issues is to study controllers working with variously configured prototypes of the new system. Studies should be designed and conducted by trained psychologists to uncover good and poor ways of using the new system. Both kinds of information will prove useful in training design.

Recommendation: *Conduct a thorough review of AAS contractor Training Plans.*

Although the contractor training plans for the ISSS were not yet available at the time of this study, both contractors discussed their general intentions with us and we reviewed the relevant specifications from the FAA. This review was enough to raise a number of questions. It seems to us that the FAA, and subsequently the contractors, have greatly underestimated the training requirements for becoming really proficient with a new system. A minimal level of being able to access each system feature (e.g., pull up a designated window) seems to be accepted as adequate. This is a far cry from being able to use the system features effectively in the course of controlling high-density traffic. In addition, the plan for training hardware and software (DCT and EST) appears neither cost-effective nor reflective of advances in training technology. We urge a serious review now, while there is still time to make corrections and be ready for ISSS introduction to the field.

Recommendation: *Initiate studies on various ACCC concepts to ascertain their effects on the controller's cognitive task.*

Research on the ACCC software, and its effects on the controller's cognitive task, is just as important as that for the ISSS. Although the software is far from complete, a number of system capabilities--such as the conflict/alert/resolution--are fairly well worked out and several extensibility scenarios exist. From reading these scenarios, it is clear that the ACCC will have a significant impact on the controller's job. It is a mistake to assume that training requirements will be minimal simply because the MMI will be unchanged.

The Technical Center offers the FAA a facility for testing out some of the concepts planned for the ACCC. Having real controllers interact with a "dummy" system, whereby a confederate simulates responses to user inputs, would provide an empirical basis for assessing the relative merits of various features. A cognitive analysis of how controllers perform under varying degrees of automation of system functions would provide greater understanding of the training and vigilance problems that will come with introduction of the ACCC software. This work would provide useful input for a much-needed rethinking of ACCC-related training requirements.

ATC Screening

The ATC Screening program is intensive and highly job-oriented (at least for en route ATC). At the same time, it is also extremely expensive. The cost of the Screen and the large proportion of failures suggest that much could be gained from using computer-based performance tests either to screen OPM register candidates before admitting them to the Academy or as a replacement for the Academy Screen.

Recommendation: *Conduct research on more cost-effective screening methods.*

The current approach--use of the OPM test, the Academy Screen, RTF, and pass-fail facility training as multiple "hurdles"--is a sound tactic for preventing acceptance of poor candidates. However, the system is an extremely expensive one both because so many people are brought into the system who do not survive and because the Academy Screen itself is very labor-intensive and expensive to run.

Recent research using microcomputers to obtain performance measures for tasks such as visualizing the intercept point of two moving objects has promise for application to ATC selection. Walter Schneider's work with a Navy air intercept task shows that the best predictor of final task performance is not initial performance level (i.e., performance in the first hour) but rather the amount of improvement over time (8-23 hours). Other work sponsored by the Army Research Institute is finding that individual differences on computer-administered perceptual motor tasks complement written aptitude measures in predicting performance in Army jobs.

Use of this kind of computer-based test for ATC selection would not require the kind of large contractor training staff now used at the Academy. The test could also be offered at multiple remote sites (e.g., regional testing centers), much as OPM and the Armed Services administer the enlistment entrance examination.

We realize that the FAA cannot simply adopt a new selection procedure without demonstrating its validity. We therefore propose initiation of a three-stage program of research and development.

1. *Develop an experimental computer-based system.*
2. *Test the prototype system with FAA Academy entrants.* This should be a sample of students going through the regular Academy Screen. Their performance on the computer-based experimental tests would not count in their selection but would be recorded for research purposes.
3. *Refine system based on results in stage 2 and administer revised tests to Academy entrants until required validity data are collected.*

Training Development

In addition to reviewing training materials, we also looked at the process whereby those materials are developed. This latter review identified several factors that can be linked to weaknesses in the resulting materials. Our two major concerns are to get more instructional design/psychology expertise on the training development staffs and to increase interaction and feedback loops between the field and the Academy Air Traffic Revision and Development section.

Recommendation: *Increase instructional design, computer science, and CBI development expertise on both the Academy and contractor sides of course development.*

Since our field visit to the Academy and the development of the training materials we reviewed, the number and level of education specialists within the R&D section have increased. This should be a step in the right direction. Having begun to address the need for this kind of expertise on the Academy staff, the next logical step would be to make similar demands of the contractor. We also recommend that the FAA ensure that the recent steps to obtain more instructional expertise on the Academy staff are adequate.

Development of good instructional materials requires not just subject matter expertise but also experienced, highly talented instructional designers. Moreover, although controllers are in the best position to say what should be covered, instructional designers/psychologists are better equipped to analyze how and in what sequence it should be presented. The two groups need to work together and on an equal footing; accordingly, the

key instructional designer for a course should be on the same GS level as the controller who is responsible for technical content. This means hiring at least a few experienced PhD-level training system designers.

Recommendation: *Ensure that adequate job task analyses are performed prior to course development and that the analyses are used by course designers.*

The characteristics of an adequate job task analysis (for course design purposes) include (1) a comprehensive listing of job activities and subactivities, and (2) identification of not only the observable job activities and subactivities, but also the mental activities that are often the hallmark of expertise. There is no need to identify instructional prerequisites to these subactivities in the job task analysis as the instructional design experts can do this when they receive the job task analysis.

The most difficult and labor-intensive part of the job task analysis is identifying the mental activities that the expert uses in performing his or her job. Such work is best done by individuals who are specialists in performing cognitive task analyses. The benefit of doing such an analysis is that these cognitive activities can then become targeted in the curriculum.

Recommendation: *Increase interaction between training developers and the field.*

The field does not seem to feel that Academy training development is sensitive to its needs. In many, if not most, cases this probably results from miscommunication or from unrealistic expectations about how quickly something can be fixed. Nevertheless, the FAA should seek out ways to increase interaction between training development staff and the field. One approach is to increase field involvement not only in tryout of completed courseware but also in reviewing course design guides prior to training development. Field personnel could also be surveyed on a continuing basis concerning how well the training materials prepare students in specific areas.

Another, less obvious, method for getting more input from the field is to involve facility personnel in the process of cognitive job/task analysis. In doing such analyses for the Air Force, we found that electronics technicians in the field were concerned that the hard parts of their job were not really covered in the standard technical training. Working intensively with our team of psychologists, they identified a whole set of skills, knowledge, and strategies needing additional training. Development of training to meet these identified needs then provides the field with the (correct) perception that they are part of the training design process.

Training Management

The HumRRO project focused upon instructional issues rather than management of ATC training. However, organizational and management issues

have profound effects on the amount and quality of instruction provided. We offer two management recommendations for the FAA's consideration.

Recommendation: *Compare mechanisms for regulating training flow across regions and disseminate procedures used by the most successful regions.*

ATC training is expensive and poses a complex management problem for the facilities. The size of that problem is greatly increased when the flow of inputs is drastically uneven. One of the centers we visited had gone for nearly two years without any developmentals and then received a class of 24. It is nearly impossible to use training resources efficiently under such circumstances. Down the road, problems are created for operational staffing as well.

We did not study the procedures that regions use to assign developmentals to facilities, but it was apparent that they differed in their ability to provide a relatively even training flow. By measuring training flows over the last several years in a sample of facilities within each region and identifying regional practices that have been most successful, the FAA can develop a model for controlling the flow of developmentals entering each facility.

Recommendation: *Elevate the status of training within the FAA by creating a Training Office at the Associate Administrator level.*

Throughout this report, we have stressed the point that the design of good ATC training requires a high level of expertise in (1) air traffic control, and (2) instructional psychology and design. Similarly, other types of technical training require the collaboration of subject matter experts, on the one hand, and people skilled in both analyzing training needs and designing and implementing training systems, on the other. It is not sufficient for these groups to discuss issues on an occasional basis, and it is counterproductive for them to argue over turf.

We would assume that the degree of fragmentation and disunity among those responsible for various aspects of air traffic controller training is not atypical of the other training programs for which the FAA is responsible. It would appear that the nature of the organizational structure contributes to this problem. Further, we note that in the FAA organization, both AT Training Requirements and Technical Training are several levels removed from their respective Associate Administrators. By following the example of the Military Services and creating a "training command" on a par with operations, the FAA would give training more visibility and a position from which it would be better able to secure and retain necessary resources.

Costs and Benefits

We have made a considerable number of recommendations for the improvement of ATC training. Having argued for the value of these changes,

we must be prepared to provide some estimates of the costs. We have attempted to do so in this section of the report.

However, by way of disclaimer, we must say that we are much more confident about estimating costs for items that would presumably be supplied on a competitive contract basis than about costs internal to the FAA. It is difficult for us to estimate, for example, costs for revisions to the DYSIM software (which would probably have to be done at the Technical Center) or costs for simulating FAA-unique equipment, such as the 300 communication system.

ATC Microcomputer Laboratory

The workstations for the microcomputer laboratory and the associated training software are central to our proposed model for ATC training. Accordingly, we present cost estimates in Table 3 both for development (including a prototype system) and for acquisition. It should be noted, however, that many of the items required for this laboratory are among those the FAA was already planning to acquire for the Advanced Automation Training System (AATS). Hence, our hardware acquisition costs overlap with those for the AATS.

Despite the fact that these workstations will be capable of supplying all the various simulator/training systems we described as well as CBI, the cost is quite modest--less than \$35,000 per three-monitor unit.

Other Costs

In Table 4 we have tried to show cost estimates for all our of our recommendations. It should be noted that some of these are total costs to be spread over several years (e.g., software development for simulations) while others are annual personnel costs (e.g., salaries for center FPLs on training department rotations). The latter are so indicated. Although there are certainly additional cost elements not considered here, such as the cost to the FAA to monitor development contracts, the basic costs for implementing our recommendations over a 3-year period (multiplying annual costs by three) are quite reasonable--less than \$22 million.

Potential Savings

It is generally easier to develop realistic estimates of costs than of savings. Nevertheless, in the latter area, we have made a few computations to help put implementation costs into perspective.

One area in which we fell fairly confident about computing savings is in the case of the Academy Screen. In our judgment, the research program we have proposed would result in a computer-based battery that could either replace the Academy Screen entirely or perform a good preselection such that

TABLE 3

Equipment and Cost for One Workstation in the Proposed ATC
Microcomputer Laboratory

•	20 MHZ microcomputer with 2 MB RAM, 40 MB hard drive, 1.2 MB floppy drive, floating point co-processor, local area network (LAN), 4 serial and 2 parallel I/O ports	\$5,000
•	Very high resolution color graphics (HRCG) controller for 1280 by 1024 pixels	2,500
•	Medium resolution color graphics (MRCG) monitor with 640 by 480 pixels and touch-sensitive screens	1,000
•	2 high-resolution color graphics (HRCG) monitors with 1280 by 1024 pixels and touch-sensitive screens	5,500
•	Digital voice output/speech recognition system	5,500
•	Interstation voice communication system with recording and playback capability, and 2 headsets with microphones	5,000
•	Computer-controlled, touch-sensitive plasma panel console with 640 by 400 pixels	3,500
•	Computer-controlled, mechanical simulation of ATC console with embedded track ball ^a	5,000
•	Stand-alone track ball ^a	200
•	Dot-matrix printer	700
•	Flight strip bay	<u>100</u>
	Cost Per Workstation	\$34,000^b

^a En route and TRACON workstations only.

^b Tower hub configuration would include a videodisc player but no mechanical operator's console. Its cost is estimated at \$29,000 per workstation.

TABLE 4

Summary of Cost Impact of Proposed Changes

Item	Cost
Improvements to DYSIM/ETG	
Software changes to run adjacent sectors	\$ 50,000
Software changes for PC keyboards	10,000
Hardware for PC remotes	264,000
6 X 22 X \$2,000 = \$264,000	
Software changes to improve realism	75,000
Software changes for freeze	25,000
Software changes for backup	50,000
Proposed ATC Computer Simulation Laboratory	
Recommended workstations	8,948,000
6 X 22 X \$34,000 = 4,488,000 (centers)	
4 X 20 X \$34,000 = 2,720,000 (TRACONS)	
2 X 30 X \$29,000 = 1,740,000 (tower hubs)	
ATC Simulation	1,000,000
Automated aid for scenario building	100,000
Keyboard/data entry training	75,000
Flightstrip marking training	150,000
Phraseology training	75,000
Aircraft ID videodisc	100,000
Tower simulation videodisc	200,000
Enhancements over a 10-year period	1,000,000
Personnel Requirements	
Two half-time FPLs per center (2 X 22 X .5 X \$55,000)	3,620,000
New training development positions	450,000
Training office HQ staff	1,500,000
Training office HQ support contracts	3,000,000
Screening Research	
3-year contract for system development & tryout	<u>750,000</u>
Total	\$21,442,000

far fewer people need to go through the Screen. Such a computer-based system should be able to collect sufficient data for a selection decision within three days at a cost of less than \$500 per applicant (on the assumption that the per day cost of testing a student would be equal to that of the current screen). When this number is compared to the current Screen cost of \$10,106 per student, the potential for dramatic cost savings is clear. If such a system had been in place instead of the present Screen in 1987, total savings for the 2,663 Academy entrants would have been more than \$25 million.

To compute potential savings in facility training, we need to make several assumptions. It is our opinion that the proposed ATC Microcomputer Laboratory, with high-quality software systems, would cut required OJT time considerably. Seattle's experience with the CERT program as well as the research literature on skill acquisition suggests that this is so. We also have recent data from a project for the Air Force in which a training system, based on a cognitive task analysis and the same training principles we espouse here, was developed (by the Learning Research and Development Center) and tried out with electronics technicians. The Air Force Human Resources Laboratory estimated that the degree of improvement in electron troubleshooting after 30 hours of problem solving on the tutor was equivalent to 48 months of on-the-job experience. We therefore feel that it would be conservative in estimating that the proposed ATC training system coupled with the recommended tightening of the en route training curriculum would reduce total training time by at least 20%.

Using the cost estimates provided to us for training an en route controller, we calculated an annual training cost of \$58,668 per center developmental. Given a year's class of 851 en route Academy graduates (FY1987 class), the 20% time savings would produce a cost savings of \$11.7 million per year.

Projected savings for terminal controllers are somewhat smaller since there is less of a simulator bottleneck in TRACONs, and tower center developmentals reach FPL more quickly than center students. Again, being conservative and estimating just a 10% savings in time to train terminal controllers, the annual training cost of \$50,000 per student results in projected annual savings of \$3,500,000 (based on an annual Academy output of 718 as in FY1987).

Our best guess, then, of the combined savings, given appropriate implementation of our recommendations, is \$13.5 million per year. (These figures would, of course, fluctuate with the number of students going through the training system.) Over the 3-year period for which we have estimated development and implementation costs, the combined projected savings would be \$40.5 million.

Given the relatively modest price tag of the proposed changes to the ATC training system, the projected cost savings are impressive. However, we believe that this is only part of the picture. The motivation behind our recommendations is to improve the product of the training system. Here, we believe our recommendations would have the most effect. In addition

producing more skilled controllers, our model ATC training program would be a much more satisfying program for the developmental. By eliminating fragmentation, wasted time, and inadequate direction, and by introducing higher quality training materials and more meaningful practice opportunities, these recommendations should make ATC training a positive, as well as a challenging, experience. This in turn should yield benefits in terms of the developmental's attitude toward the FAA. It is difficult to assign a value to these improvements in controller skill and morale, but they are important nevertheless, and certainly should receive serious consideration in weighing these recommendations.