TABLE 1. THEORETICAL MIXES OF TRAINING RESOURCES FOR ACHIEVING LIMITED TRAINING OBJECTIVES

MIX NO.	CLASSROOM	SIMULATOR	OPERATIONAL SYSTEM
1	facts and knowledge	-	Familiarization Practice to Criterion* Certification
2	facts and knowledge	Familiarization	Practice to Criterion* Certification
3	facts and knowledge	Familiarization Initial Practice	Practice to Criterion* Certification
4	facts and knowledge	Familiarization Practice to Criterion*	Practice to Criterion Certification
5	facts and knowledge	Familiarization Practice to Criterion*	Certification
6	facts and knowledge	Familiarization Practice to Criterion* Certification	-

*x Successful performances

For example, mix number one is a common pattern in many training programs. The facts and knowledge aspects of specific skill are learned in the classroom. Familiarization, which involves an instructor demonstrating or guiding the student through the initial trials, is performed on the operational system. Practice to criterion and certification also take place on the operational system. Simulators are not used in this mix of training resources.

With mix number three, familiarization and initial practice occur in the simulator, and then additional practice to criterion and certification take place in the operational system. This pattern is frequently observed in trainer utilization programs.

Mix number four is a mix that is seldom observed. Familiarization takes place in the simulator, then the simulator is used for practicing the skill until criterion performance is achieved. This criterion may be defined as one errorless performance in the simulator, or perhaps, five consecutive errorless performances. Upon achieving criterion performance, the student or team proceeds to practice, as required, on the operational system, then passes the certification, or check hop, on the operational system.

Under certain circumstances mix number six is being used. All three phases are conducted in the simulator. This mix may be selected, when the skill or procedure to be practiced cannot be performed in the operational system, due to hazards or because targets, etc. cannot be obtained.

For what purposes should simulators be used? In what manner should they be employed? There are traditional answers to these questions. Yet, traditional answers result in the use of simulators primarily for the familiarization phase of a training program. We can build bigger and better simulators, but this does not guarantee that new patterns of use will result. The curricula for trainers must be innovative and must be developed with the same degree of professionalism used in the design of the simulator hardware.

We need to view a simulator as one element in a training system. We need to clearly identify the mix of training resources in this system, to identify the specific functions to be performed by the simulator. As the simulator is being developed we need to develop the detailed curriculum materials, and then train instructors in the use of these materials. And finally, we need to measure the utility of this package, simulators and curricula, in terms of student achievement and transfer of training, as specified in the training objectives.

TRADEOFF CRITERIA FOR SPECIFICATION OF PRIME OR SIMULATED COMPUTERS IN TRAINING DEVICES

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INTRODUCTION

Prior to the establishment of a simulator specification for a new system, a comprehensive analysis of the training requirements and the intended utilization environments must be accomplished in order to assure the training effectiveness of the resulting hardware design. Too frequently the exigencies of time and budgets result in shortcuts or guesstimates replacing the required analysis and planning. The result is an underestimate of the required training requirements and the functional performance capability of training equipment. Similarly, we tend to forget that each new weapon system and its integral subsystems must be significantly different in capability and performance, than its predecessor, in order to exist in today's restrictive and highly competitive defense budget environment. For a program to have survived requires, not only, a significant step function improvement, but also requires that the threat environment, in which it is to perform, must have achieved a similar increase in sophistication or complexity. Unfortunately, we have not been able to re-design the man to achieve step function increases in capability and performance. The logical alternative has been to imbed in almost every system highspeed computational elements to perform those logical and analytical functions, which man has found himself incapable to perform, in the increasingly more complex tactical environment. By design intent, each system's resultant utilization or employment is significantly different than its most similar predecessor. Similarly, the training requirements are significantly different. For the same reason that shortcuts are not taken in prime equipment design, shortcuts must not be taken in the analysis of training requirements upon which equipment specifications are to be based.

Properly conducted, these training requirement analyses will provide a baseline, which may identify a spectrum of hardware devices, with supporting training aids and media concepts, time-phased in implementation to support the overall training plan. It is at this point that the essential characteristics of hardware devices must be evaluated, not only, in terms of functional performance, but availability for and adaptability to the training program, and its curriculum requirements. Decisions must now be made on hardware solutions to the functional performance requirements. Invariably, one of the most difficult hardware decisions to be made, when specifying a simulation device, is the tradeoff between utilization of the prime system computational elements and its related software, and the simulation of the prime system computer and its software.

PRIME VS SIMULATED COMPUTER TRADEOFF CRITERIA

The tradeoff process involved in selection of the hardware solution to a functional performance requirement is not a clean-cut process. Decision processes range from the highly objective, employing rigorous analytical techniques to the highly subjective substantiated only by human emotions. We have come to the conclusion that one of the main subjective reasons for using a prime computer in a trainer is the hope this would provide a more direct method of transferring software changes from the prime system to the trainer than if the computer were simulated. When we talk about using the prime system in the trainer we are implicitly including the prime software. No doubt bitter experience with prime system software change control in the past justifies looking for drastic solutions to the problem as it affects the trainer. Fortunately the software concern is not the only criteria for specification of prime equipment. During the decision process this fear becomes only a subset of four major criteria groups which emerge as cornerstones for the ultimate decision. For tradeoff convenience these criteria groupings are categorized in figure 1 in terms of the trainer's utilization, time constraints, technical considerations, and risks.

UTILIZATION RELATED CRITERIA

- End Use Intent
- Colateral Use Intent

TIME RELATED CRITERIA

- Training Need Date
- Equipment Availability
- Software Availability
- Flexibility for Change

TECHNICALLY RELATED CRITERIA

- Technical Approach
- Fidelity
- Cost

RISK RELATED CRITERIA

- Contracting Risk
- Supportability

Tradeoff Criteria Grouping

Figure 1. Criteria Groupings

If each criteria group is rationally analyzed and evaluated a pattern emerges that can provide insight into the prime vs simulated computer-decision process. Some typical tradeoff processes are provided as examples of situations that contribute to the final decision on the hardware configuration.

OPERATIONAL EQUIPMENT. In some cases, an operational system may be used in total as its own training device, which settles the question of the prime computer. For example, in large ground-based or shipborne weapon systems there is a great advantage to having the ability to input simulated inputs into the sensors, so that training can be accomplished in the operational environment. Typically, such a capability is desired for tactics training, and for refresher rather than basic training. The simulated inputs can be a very desirable alternate to flying expensive real raids against the system. If the original prime system specifications cover this type of capability, then the system will be designed with the necessary added computer speed, memory capacity, computer programs, peripheral devices, and special sensor simulation hardware to accomplish it. If the system is not originally designed, with this capability included, it may be possible to add on the necessary storage, input/output devices, etc. at a later time. The operational system is thus itself a training device, which obviously requires the total utilization of the prime computer.

SIMULATED OPERATIONAL EQUIPMENT. The simulation of an operational system presents a less clear decision-process on utilization of the prime computer. Because this class of simulator typically has pre-formulated data on the characteristics of the trainer world; e.g., target and emitter characteristics, navigational data, range and bearing relationships, etc., much of the prime computer capacity and software routines are not fully utilized, or even needed. This partial utilization of computational capacity then becomes both an equipment cost and technical penalty associated with the device. This potential excess computational capacity then presents an interesting anomaly. If a decision were made to utilize this capability then the existing prime software must be modified to include trainer peculiar routines. This defeats one of the implicit reasons for prime computer utilization--use of prime software.

A more subtle tradeoff is presented when a collateral utilization of the trainer is implicitly intended. This occurs, for example, when modification of prime equipment software is a major operational or a post engineering development concern. This use in technical evolution of prime equipment capabilities is a trainer utilization that is frequently overlooked, but provides a weighting factor in favor of the prime computer system.

A similar hidden objective, that is frequently satisfied by a trainer, is the evolution or refinement of operational tactics. Although, not normally encouraged, a totally simulated operational computer and software system does provide a software modification capability to rapidly evaluate tactics against new threats. This capability is expecially valuable in the simulation of EW environments or evaluation/assessment of actual missions.

MAINTENANCE TRAINERS. Often overlooked in the tradeoffs of prime and simulated computer equipment is the maintenance trainer, where normal inclination has tended toward almost predetermined use of prime hardware. Often this has resulted from an unclear definition of the trainer's major intended use. The use of a total system in a "hot mockup" configuration is the frequent offender, when the intended system use might only be to train personnel, on built-in-test accessing and display interpretation. Realistically conducted tradeoffs invariably tend toward simulation of the prime computer for built-in-test and system fault insertion simulation.

TIME CRITERIA VS COMPUTER DECISION

Assuming that a detailed training plan has been postulated, training need dates usually dictate trainers ahead of(ideal), or at least concurrent (acceptable), with system delivery, or at the very worst not more than three months subsequent. Unfortunately, these time requirements are not always met. The principal constraint is the necessity for the near concurrent development of the prime system and its trainer.

What are the effects of this design concurrency upon the computer tradeoff decision? Let us now assume it appears to make sense to use the prime system computer in the trainer, at least, from the technical standpoint, and see what effect the prime system and trainer development schedules might have on the decision.

One factor is change control. If the trainer schedule is nearly concurrent, with that of the prime system, the problem of keeping the trainer and prime system programs looking alike is most severe because of the high rate of changes. This rate of change would appear to reinforce the decision to use the prime system computer in the trainer. But, invariably the computer hardware is a developmental model along with the rest of the prime system. The computer availability, for use in checking out the software, and the hardware interfaces in the prime system and trainer can become of much greater concern than the configuration problem. Even if it appears feasible to acquire an early model of the computer into the trainer, for checkout purposes, there is bound to be a very high risk. First models have bugs, suffer from documentation inadequacies, and incur reliability problems until the basic design has accumulated a large amount of operating time. Considering that the checkout schedules of the trainer have a higher order effect upon total costs, than change control, it becomes very questionable whether one should ever risk a developmental computer in a trainer.

However, these problems can be circumvented to a large extent by an alternate approach. The main benefit gained by specifying the prime computer in the trainer is the carryover of the programs, not the hardware. It follows that an ideal solution would be to use an entirely different off-the-shelf computer in the trainer, but retain the ability to translate the prime system programs into the language of the trainer computer. This approach has been quite successfully implemented in recent complex simulators such as Devices 15C8, 15C8A, 15C9, and 15C9A.

TECHNICAL CRITERIA VS COMPUTER DECISION

Attempting to interface a prime system computer with a trainer can involve severe technical problems. Since, by their nature, these problems are subtle and complex they cannot be discussed very thoroughly in the paper. However, at least a few highlights are worth presenting. The objective will be not to advance any particular technical theory or methodology. Instead, emphasized will be the fact that, although the role of a computer and its programs in a system may at times appear to be straightforward, there is an excellent chance that the involvement is much more intricate than it appears to be. This fact may help caution us to be wary of innocently imposing design requirements, which contain hidden traps.

It is dangerous to underestimate the complexity of the computer's role in a prime system when considering transplanting the computer into a trainer. On the other hand, particularly, because of the difficulties involved in maintaining sofware change control, between the trainer and the prime system, there is good justification for attempting to use the same software in the prime system and the trainer. The use of a trainer integral software translation approach offers considerable promise of solving a good part of the problem without incurring many of the risks, particularly, when the trainer and prime systems development heavily overlap.

One of the principal characteristics of the computer in a prime system is its role as a loop closer. In fact, a programable digital computer has the advantage over an analog computer in that it can be shared so as to close several loops simultaneously. This immediately begins to suffest that in a complex weapons system the computer may become imbedded in the system in a complicated manner. To start with a simple situation, figure 2a represents a familiar loop. This is most significant to the user, since in addition to himself, and the computer it involves the equipment, which normally occupies all of his attention. Disregarding any other factors, this makes it an ideal loop to transplant from the prime system to the trainer.

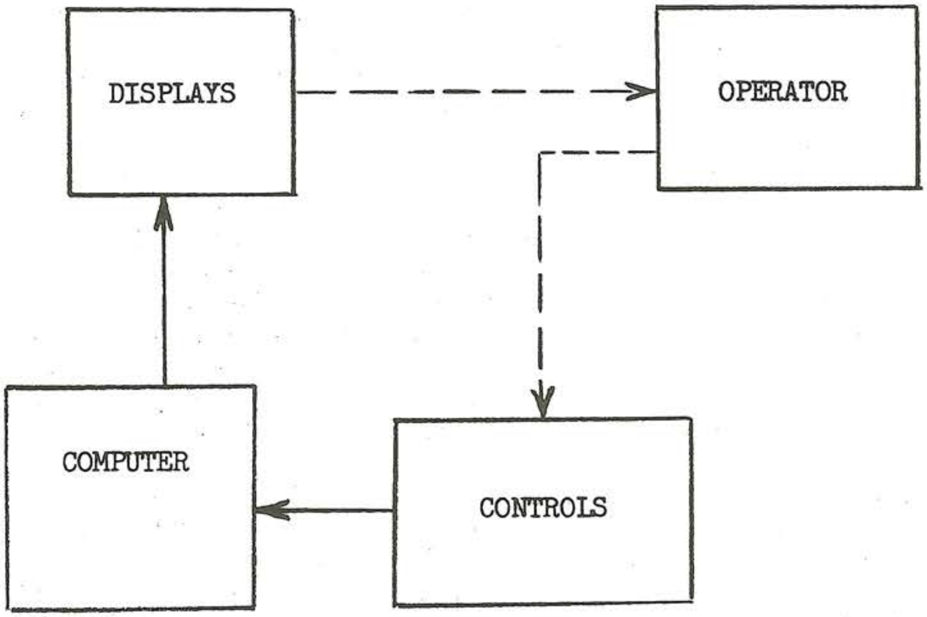

Figure 2a. Simple Loop Through the Operator

The problems start coming in from other loops, which are largely submerged. Figure 2b represents a simplified diagram of such a loop. The box marked "A" in the figure receives signals from the sensors (several kinds), performs some hard-wired functions, and passes the data to the computer for further processing. The loop continues with display of the processed data to the operator, who makes decisions, based on what he sees, and hears, and returns controls to the computer. The computer then sends signals to the box marked "B", which generates control signals for the receivers.

If the prime computer is used in the trainer, simulated data identical in certain specific respects to the data generated by box "A" in the actual system must be fed into the computer. The exact characteristics of this data must be known in order to provide adequate realism to the operator. These characteristics may include pulse repetition rates, pulse widths, frequencies, and the like. Moreover, it is important to know what these parameters really are in the system, as opposed to the design objectives contained in the original prime system specification. The difference between these stated requirements, and the performance achieved, can represent a considerable difference in the cost of simulating the interface and resultant trainer fidelity. At the output of the computer to box "B" another situation exists. Although, in the trainer there is really no physical box "B" to control the computer must continued to stupidly send out control signals anyway, as it was programed. Again, this signal interface must be understood precisely, if one is to know how much of it can be ignored, and also know how to process the rest of it into a form suitable to send back through the simulated sensor and box "A". This assumes that prime hardware would not be used to simulate boxes "A" and "B," and the sensors, because simulating them in a trainer computer, with some added special hardware is generally cost-effective. However, as this discussion indicates, without adequate information on the interface requirements, there is a technical advantage in leaving the prime computer out of the trainer, and simulating the prime computer and its software by trainer peculiar software.

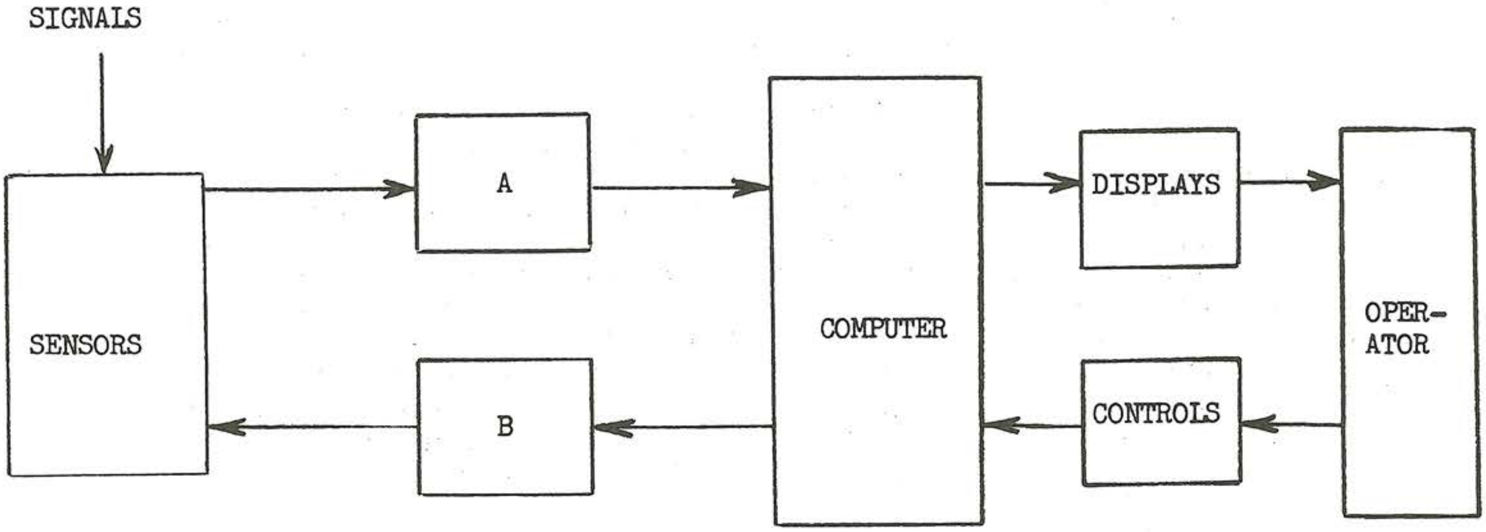

Figure 2b. More Complex Loop with Submerged Elements

Figure 2. Computer Interface Loops

RISK CRITERIA VS COMPUTER DECISION

The dangers of underestimating the prime computer's role have been emphasized in terms of its interface requirements. However, when we look in general at the risks of specifying a trainer the risks segment themselves into two classes.

1. The lowest risk class is the definition of generic trainer requirements, such as problem formulation, freeze and replay capability, trainer world size, instructor displays, exercise and trainer world content, and selection of prime system functions essential for simulation. These requirements are generally satisfiable with reasonable mutual contracting risk.

2. The second risk class represents the much higher mutual contracting risk, and is the more difficult to quantify. The simulation requirements for an operational system are generally easy to specify if one addresses only the sensor stimuli and the operator's display and interactive system controls.

What is most difficult to specify,because of its evolutionary nature, is the internal system interfaces with the computer and its software system. The definition of these interfaces is a complex and iterative task — one not even totally completed until production delivery of the prime system (if even then). What generally occurs, at this point, in the requirements process is the specification of the prime computer system on the premise that the prime manufacturer solves his interface problem, and the trainer contractor can then merely react and modify his device. What tends to be overlooked in the specification requirements for the simulator is that for each prime computer interface there is at least one and generally two interfaces — hardware and software. The simulation and monitorship functions required to accomplish the trainer peculiar functions of problem formulation, exercise and replay require well-defined interfaces to achieve the required trainer performance fidelity. Modification of hardware interfaces becomes costly and schedule restrictive; software on the other hand tends to be readily modifiable. This continual flow of interface changes affecting established trainer baselines inevitably impact program cost and schedules, and ultimately result in tradeoffs on device fidelity and configuration compatibility with the prime system. The resultant mutual contracting risk resolves itself into schedule adjustments, cost increases and specification modification, none of which totally satisfies the initial contracting intents.

If it is assumed that a decision has been made to simulate the prime computer functions, then does not the same contracting risks evolve, as with prime hardware? The answer is a resounding NO. The requirement for explicit interface data is drastically reduced, internal trainer interfaces are reduced, trainer design can be accomplished in parallel with the prime system, and prime system specifications and performance requirements become a trainer design reference. The cost and schedule effects that result from prime system interface changes are avoided. What now results is a shift of mutual contract risk, from those related to the continual prime system design changes, to those of less frequent prime system performance changes. This provides both parties the design flexibility, and most effective use of program funds to maintain trainer/prime system configuration compatibility, and to achieve planned training need dates.

In summary, figure 4 depicts the relationships of aggregate risk of specifying a trainer hardware configuration, when interface data is evolutionary. Risk is minimized by simulation of the computer subsystem during early stages of parallel development. The correlary condition is mutual risk increases whenever prime hardware is specified for trainer utilization, when the prime system is under parallel development.

A major risk area frequently overlooked is the supportability of a trainer after introduction in the training environment. Trainer availability is a direct result of its reliability and personnel ability to maintain its performance in an operational environment. Careful tradeoffs must be accomplished to ensure the added trainer complexity,resulting from imbedding prime system computational capability,does not seriously complicate troubleshooting and maintenance capability. Hidden factors that degrade true training availability, such as prime system support equipment dependency, spares priorities, modification lead-times, prime and trainer computer system maintenance priorities, are problems that must be realistically evaluated. It is obvious that many of these trainer availability limiting factors are minimized when only a single non-prime hardware computational element contributes to the true availability.

SUMMARY

The tradeoffs which culminate in the decision whether to utilize prime system computer (and software), or to simulate its functions by trainer peculiar techniques are not clear-cut. The use, time, technical and risk-related criteria must be objectively evaluated for each particular trainer application. Figure 3 depicts a logical sequence related with salient factors that influence the tradeoff decision of criteria analysis. This listing can provide the basis upon which the final tradeoff decisions can be based. As more tradeoffs are conducted on future simulation device requirements, quantitative relationships should emerge, which will simplify, and add increasing creditability to the decision process.

In the actual tradeoffs, which have been conducted, the single most important element that influences the various decision criteria is time. If required training need dates are to be met the parallel development of both the prime system, and the trainer is required. This program requirement imposed in tradeoff analyses invariably results in decisions tending toward simulation of prime equipment computer functions.

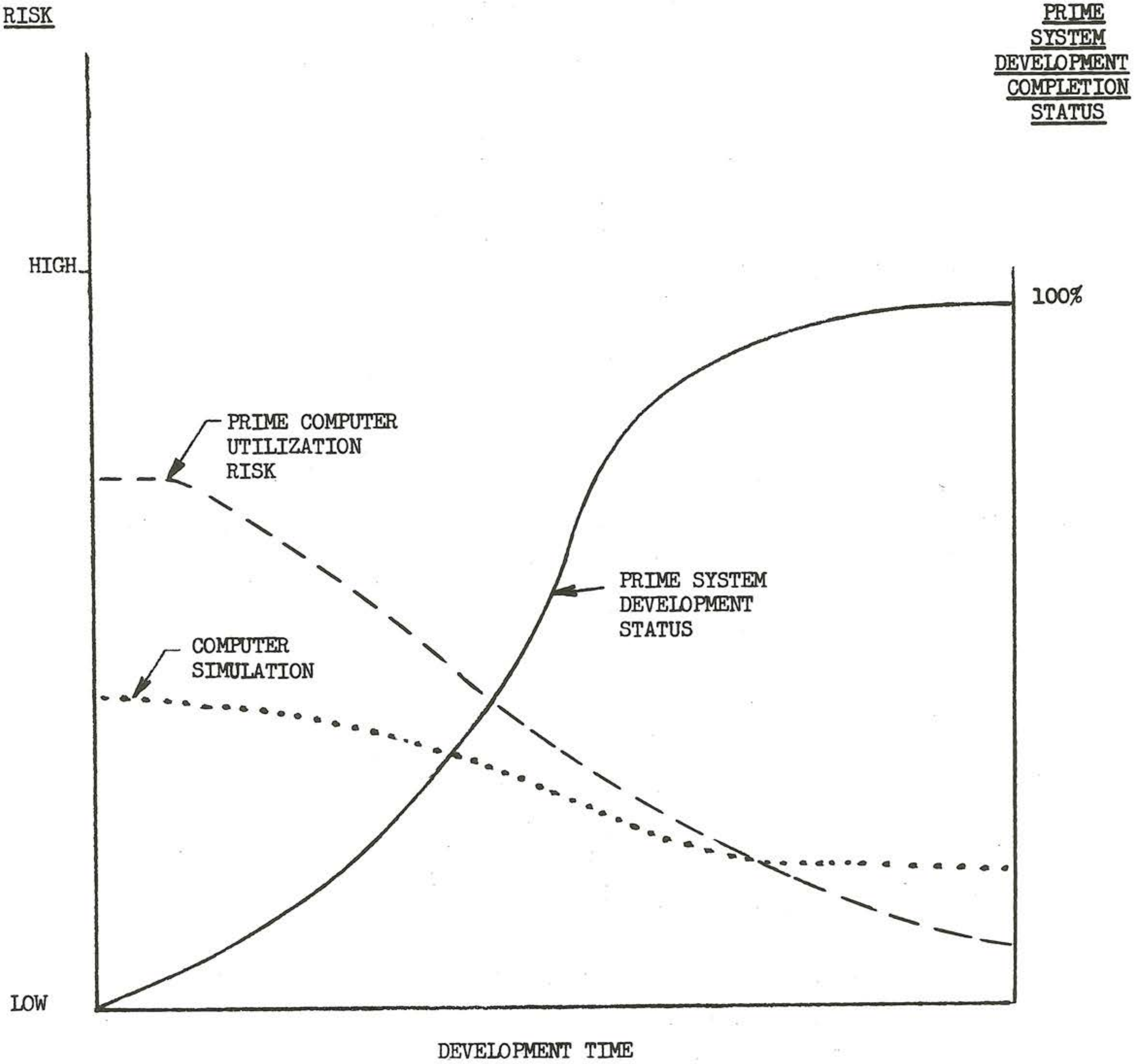

Figure 3. Composite Risk vs Prime System/Trainer Development Schedule

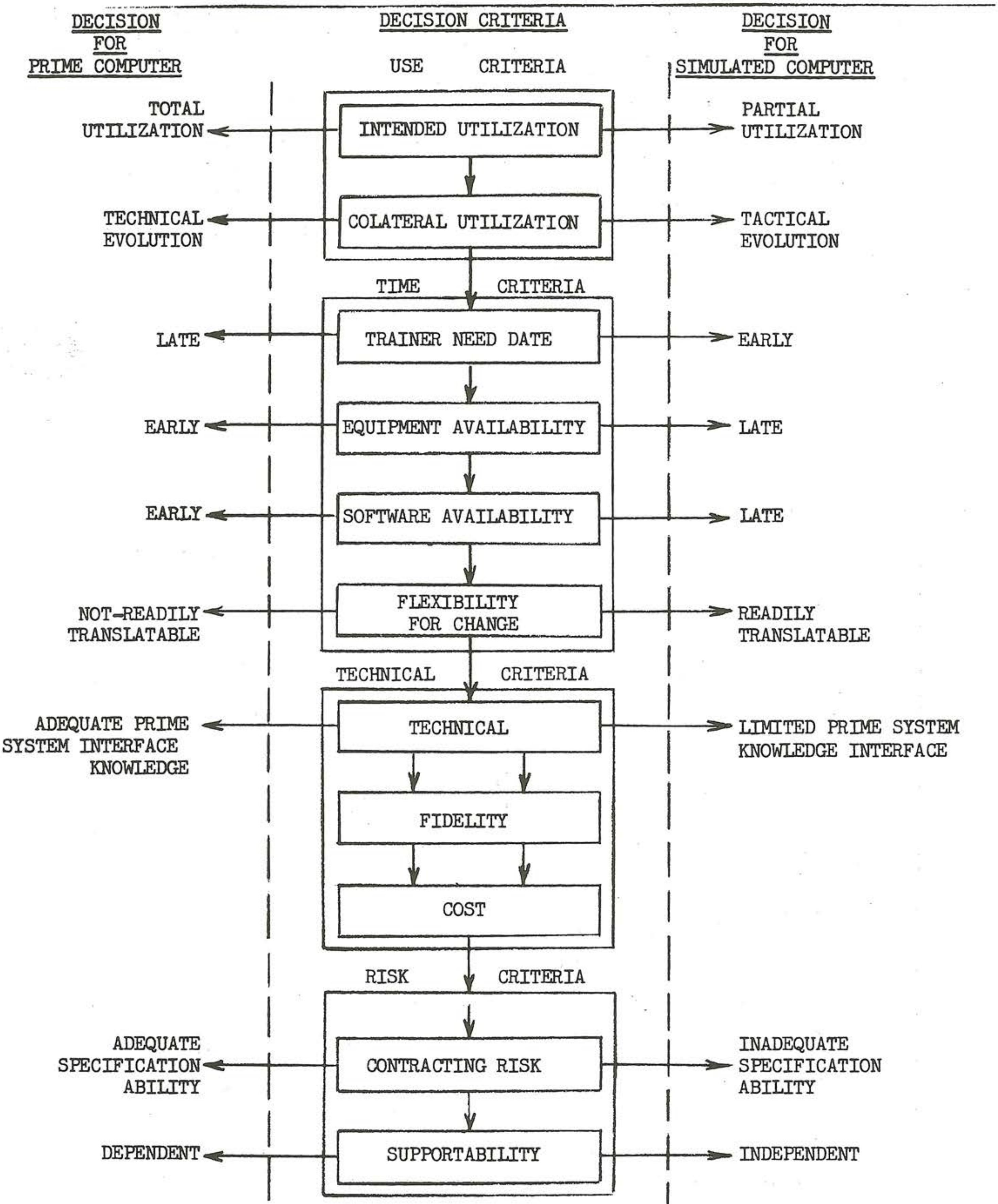

Figure 4. Criteria Analysis Relationships

INSTRUCTOR CONSOLE INSTRUMENT SIMULATION

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INTRODUCTION

The application of computer-generated displays to training device instructor consoles was until recently a relatively unexplored area. The traditional use of digital computers for control of instructor console instrumentation, such as repeater instruments, pushbuttons and indicator lamps, is well known in the training device industry. Several introductory attempts at improving speed of simulation response and extending the content of instructor communication, with the simulation computer, have utilized computer generated alphanumeric display. However, utilizations of highly interactive, computer-generated graphic displays in instructor console applications have not yet been developed.

The objective of the aircraft instrument simulation on the Naval Training Device Center's in-house display system was to verify the capability of using interactive, computer-generated graphic displays in instructor console applications. The concept was verified by satisfactorily simulating the instructor console instruments for the F4 Phantom flight simulation on the TRADEC display system. (TRADEC)is an acronym for the in-house Training Device Computer facility at the Naval Training Device Center (NAVTRADEVCEN).

The F4 flight instruments cover the full range of complexity and diversity found in modern simulator systems. In addition to the feasibility demonstration, the display programs developed for simulating the individual instruments will provide facilities to perform experiments in man-machine interface, instructor console design, display format, and instructor communications.

Availability of the TRADEC display system interfaced to the Sigma 7 computer provided an excellent opportunity to accomplish a complete simulation of the TRADEC F4 instructor console on the display system.

SYSTEM DESCRIPTION

TRADEC Simulation Facility. The TRADEC simulation facility consists of a Sigma 7 computer, a full complement of general-purpose peripheral equipment, a simulated F4 Phantom cockpit, mounted on a four-degree-of-freedom motion platform, an operator's control console, and a display system with a display computer and two display terminals. See figure 1 for a block diagram of this system's configuration.

Display System. The display system was manufactured by Information Displays, Inc., and is known as the IDIIOM (IDI Input Output Machine). It uses: (1) A Varian DATA 620/i computer as a buffer for display programs; (2) a display processing unit to execute the display program; (3) function generators; and, (4) display consoles.

1. The DATA 620/i mini-computer core memory has a 16-bit word length with a 1.8 microsecond full-cycle time. Present memory capacity is 8,192 words. This computer controls the interface with the Sigma 7 and also controls the display processor.

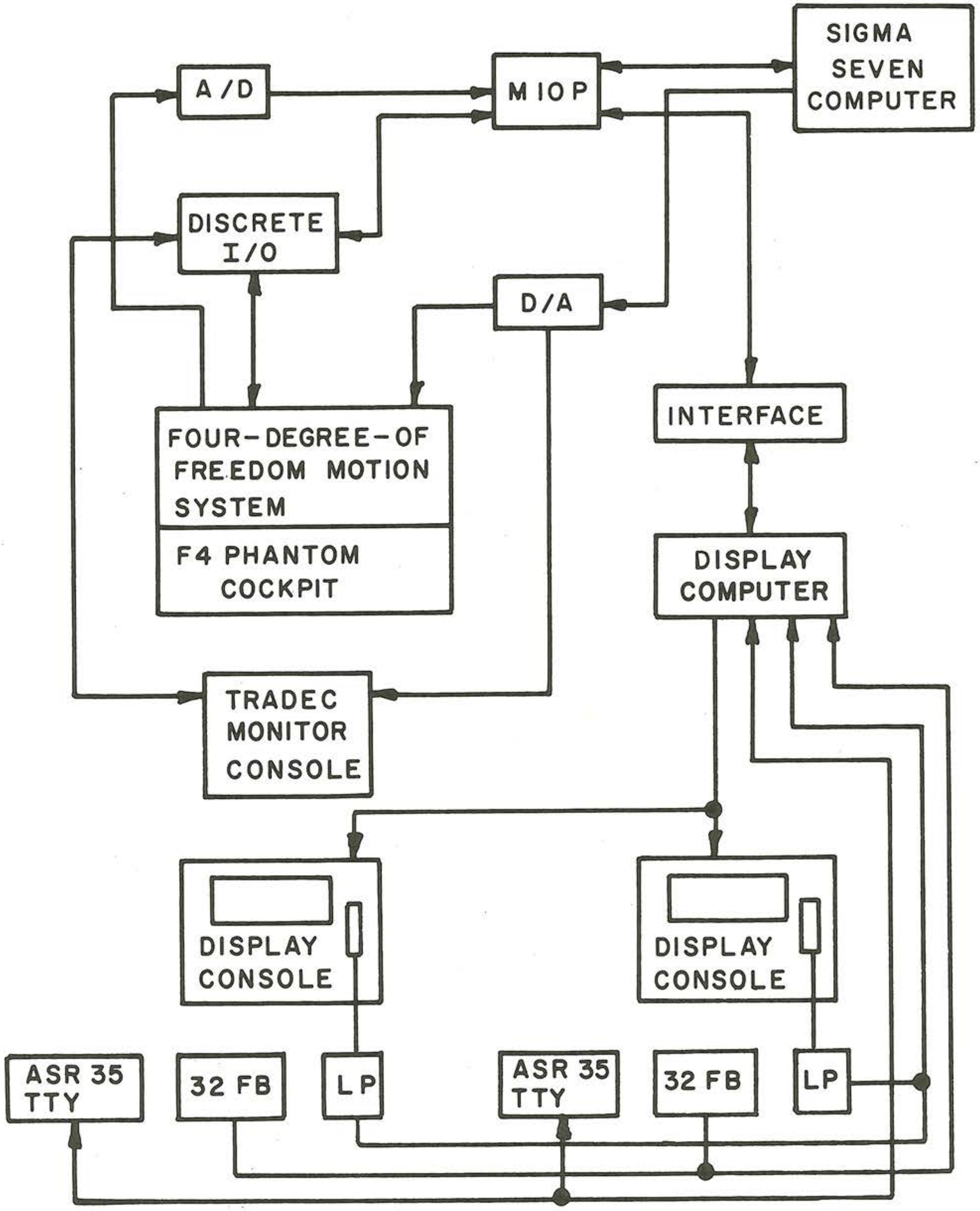

Figure 1. Block Diagram of System Configuration, NAVTRADEVCEN In-House Simulation Facility

2. The display processor repetitively executes a program of display instructions to provide continuous updating of the CRT phosphors. All communication between the DATA 620/i and the vector and character generators pass through the display processor.

3. The function generator units accept input from the display processor and supply the signals required to drive the display consoles. Included in these units are character generators, vector generator and beam positioning circuits, circle generators, intensity control circuits, and line drivers.

4. Each terminal has a 21-inch CRT with 13-inch square accurate display area. There are 1024 addressable points along each axis. The displays are presented as a sequence of blanked and intensified vectors. This type of display is called a calligraphic, or stroke drawing display. Each terminal is also provided a light-pen, 32 function buttons with programmable lamp indicators and an ASR teletype for input/output to the display computer.

Interface between Sigma 7 and DATA 620/i. The Sigma 7 interface communicates with the DATA 620/i through programmed I/O. Transfer rates of up to 30,000 eight-bit bytes per second are possible when block transfers are processed. Bi-directional external interrupts are provided for each computer, and data transfers may be initiated on either side of the interface.

TRADEC Instructor Console. The F4 monitor console enables the instructor or operator to control and observe the simulation problem. There are three panels at the monitor console:

a. The motion control panel, which provides complete control of the hydraulic power system and motion actuators.

b. A switch panel which generates and displays computer discrete inputs and outputs. The panel contains a bank of 64 backlighted pushbuttons, which service both as indicators and switches, and are used to control the simulation's progress.

c. The instrument panel, which houses a set of 19 cockpit instruments for monitoring simulation performances. For a view of the nineteen repeater type instruments, see figure 2.

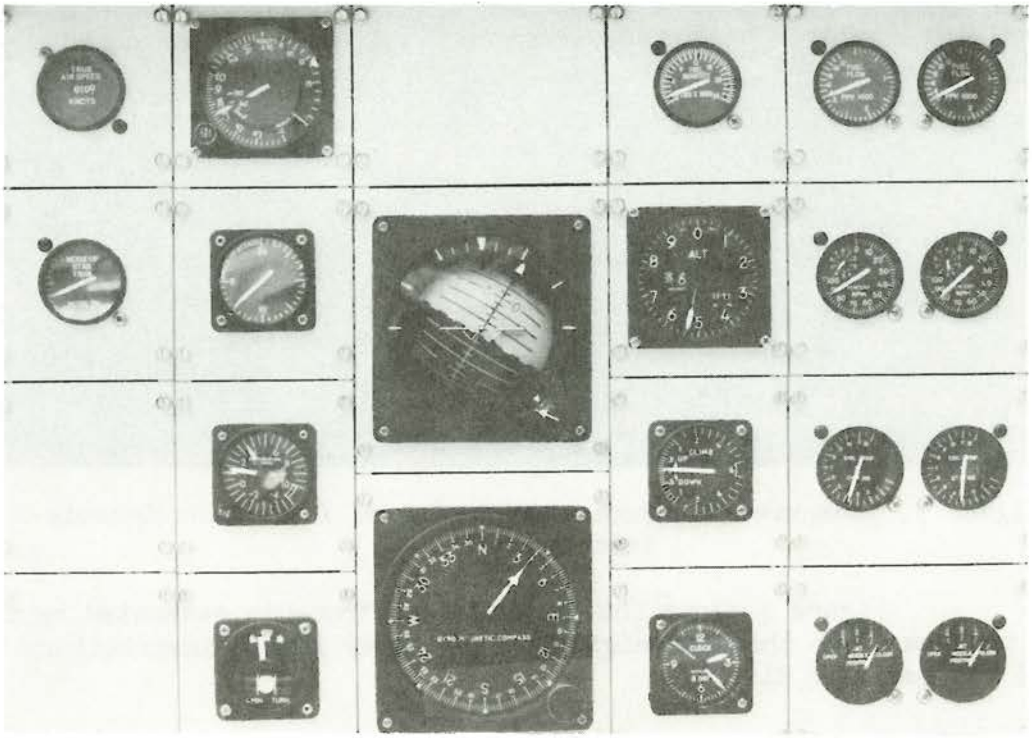

Figure 2. Instrument Panel, TRADEC Instructor Console

PROGRAMMING

Programming for the display system is more complex than single processor computer programming, since the display processor represents a second computer-like device operating out of computer memory. When the display system operates in a stand-alone mode, with no access to the Sigma 7 interface, two separate programs are simultaneously executed to provide dynamic display. With the interface connected, three programs are active at the same time. The three programs are: (1) The display program; (2) the DATA 620/i control program; and, (3) the Sigma 7 simulation and communication program.

1. Display Program. This program controls the analog vector and character generators to sequentially draw a picture on the CRT. The instructions in this program are similar to computer instructions, but result in changes to the CRT electron beam, changes in the instruction execution sequence, or changes in the internal state of the display processor.

Display instructions provide absolute and relative positioning, vector generation, point plotting, and stroke type characters. Vectors may be drawn with four levels of intensity, in one of the four vector formats: solid, dot, dash and dot-dash. Control type instructions in the display program provide display subroutining, conditional jumps, indexing, and refresh frame rate control.

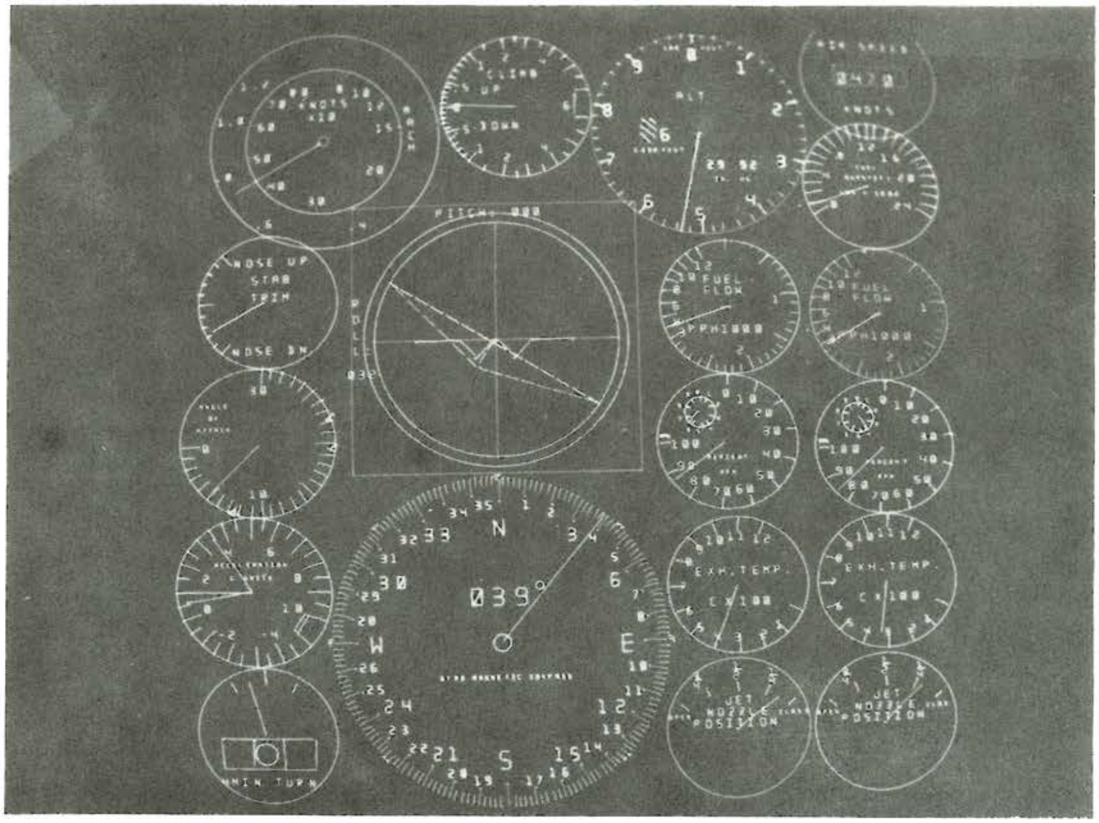

Figure 3. Computer-Generated Simulation of Instructor Console Instruments

Figure 3 shows the 19 flight instruments generated by the display program. Two thousand eight-hundred sixty 16-bit instructions were required to draw this display.

2. DATA 620/i Control Program. This program is responsible for servicing display console inputs from the programmable function buttons and light-pens. It converts instructor inputs into changes to the display program. These modifications result in the reconfiguration of the display format on the display scope. The reconfiguration is effected by:

a. Push-button selection or deletion of individual instruments on the display scope (using the function keyboard).

b. Light-pen positioning of individual instruments on the display scope.

The DATA 620/i control program contains a communications section to control the Sigma 7 to IDIIOM interface and provide real-time input of a table of F4 instrument parameters. The program is activated by interrupts from the Sigma 7, which cause suspension of the control program while inputs from the Sigma 7 are transferred. When the input transfers are completed, the control program resumes operation and modifies the display program according to the latest Sigma 7 inputs. These modifications provide the dynamics to the various instrument indicators. The communications section is activated during each fifty millisecond iteration of the F4 program cycle. The DATA 620/i control program occupies 3,415 memory locations in core memory.

3. Sigma 7 Program. An active F4 simulation program in the Sigma 7 dynamically updates the display computer memory with current values of instrument parameters. The updated parameters are required to produce the appropriate motion of the instrument dials and indicators. To enable this transmission, the standard F4 simulation was modified as follows:

a. A new program module for constructing a properly formatted output buffer was added to the F4 program.

b. A routine to extract Euler angles from direction cosines was added to the F4 program.

c. Various standard F4 program modules, including the real-time input-output, the system parameter, and the aircraft instrument program modules, were modified.

RESULTS

All nineteen repeater instruments were simulated on the display console in as near identical format as possible using the display. The instruments were interfaced with the F4 flight simulation program, with good visual correspondence between the instructor console flight instruments and the corresponding CRT displays of those instruments.

Figures 2 and 3 demonstrate the visual correlation between the display simulation and the instructor console. The two photographs were obtained with the flight simulator in the freeze mode; i.e., the flight program was halted during a flight maneuver, and held "frozen" with all parameters fixed. This allowed a static comparison between corresponding instruments. Good correlations can be seen.

A good dynamic correspondence was observed also during simulated flight maneuvers. The various instrument component motions (such as those of the rotating, counter-type decimal indicators, the pointers, etc.) were simulated in real-time.

The function keyboard permitted the operator to select for viewing those instruments he wished to observe. Any, or all instruments could be selected for viewing. The operator could also delete any or all instruments from the screen using the function key-board.

The operator was allowed to re-position the instruments on the display scope at will. The program remembered the latest position of each instrument after its move with the light-pen. The most recent position coordinates were recalled from memory following a "delete" operation followed by a subsequent "restore" operation.

The function keyboard provided an additional operator-control feature: The choice of either synchronous or asynchronous display refresh rate. Depressing the function key labeled "S" lock-synchronized the frame repetition rate to the power line frequency, or a sub-multiple thereof; while depressing the key labeled "A" allowed the frame rate to be a function of the display program length. To display a large number of instruments, it was advantageous to select an asynchronous refresh rate to decrease the flicker effect. On the other hand, to display only a few instruments, the synchronous refresh rate was preferred to prevent excessive brightness on the scope.

CONCLUSIONS

The primary task in meeting the objectives of this study was to duplicate the functions of the present TRADEC F4 instructor console on the in-house computer-generated display system. The instruments have been successfully simulated and interfaced to the F4 program. The control functions represented by sixty-four backlighted pushbuttons on the conventional instructor's console still remain to be simulated. These will probably be represented by a light-pen selectable menu of options around the periphery of the display screen.

The second objective of this study was to develop a control program to allow interactive control of display formats. This has been done in the present version of the control program. The program can easily be modified, and changes, or additions, will be made to incorporate improvements throughout the remainder of the project.

Even in its incomplete form, the present version of the instrument simulation program has demonstrated several potential future applications. The instrument simulation has already been used by simulation technicians in verification and alignment of both on-board simulator instruments and instructor console repeater instruments. The displayed indication is derived directly by simulation parameters within the TRADEC Sigma 7 program and provides direct access to the parameters without distribution to the analog instrument outputs. For this reason, the display simulation provides a useful backup and check on the indications of the actual instruments.

The ease of display control will provide research capability for human factors use in instructor task definition. The flexibility in reconfiguration of display formats on the simulated console provides a useful tool for human factors studies in defining the instructor tasks in controlling and evaluating trainee performance. An instructor can reposition instruments on the display to provide close monitoring of groups of instruments. Such grouping is not available on a conventional console, and regrouping would require considerable labor in physically repositioning instruments on the instrument panel.

Completion of the simulation of the F4 instructor console instruments and controls on the in-house display will represent one of the first successful applications of interactive computer-generated displays in a real-time aircraft training device simulator. The simulation will provide excellent flexibility and improved performance in instructor monitoring and control functions at slight increase in cost in the loading of the aircraft simulation program. The interface communication between the simulation computer and the display system is also very light. Transmission of the updated table of simulator parameters must be accomplished each simulator program cycle, but this is only 34 sixteen-bit words each fifty milliseconds, or a total of 680 words per second. This is extremely light considering that a transfer rate of 15,000 words per second is achievable through the interface.

Incorporation of similar consoles in future training devices will provide standardization in hardware, while increasing performance. Hardware standardizations will result in savings in maintenance, provisioning, and training for maintenance and operator personnel.

STATUS OF COMPUTER-GENERATED IMAGERY FOR VISUAL SIMULATION

MR. M. G. GILLILAND
Apollo & Ground Systems Department
General Electric Company

The basic task of visual simulation for training is the provision of out-the-window scenes for the pilot which respond realistically to his control movements. Many requirements are placed on the visual scene so produced, the most important being that the scene respond in real time and that it provide the appropriate visual scene to the pilot to make him think that he is actually traveling through the simulated environment.

Computer Generated Imagery (CGI) technology approaches the task of providing suitable out-the-window scenes by using special purpose digital computing hardware to scan a mathematical environment model. The scene so produced is presented on a television output device, with the picture being updated thirty times per second.

CGI systems possess certain significant capabilities not easily attainable with other visual simulation techniques. Among these are the ability to move in the environment with full six degrees of freedom, availability of an extensive operating area within the environment, and freedom from optical or mechanical system limitations. Because the environment is really a mathematical description in computer memory, there is no limitation on where the pilot can go or on what attitude he can get into. Since the mathematical scanning process used to present the scenes on the display device is performed with a theoretically infinitely-small aperture, there are no depth-of-field problems. The image is in focus throughout the scene.

Since several adjacent views of the environment can be computed from the same eye point, it is possible to juxtapose field-of-view segments to provide a viewing window of almost any desired angular extent. The problems of sensing the image, however, are greatly simplified by the freedom from limitation on look-direction inherent in CGI systems. The principles upon which a CGI system operates are illustrated in figure 1.

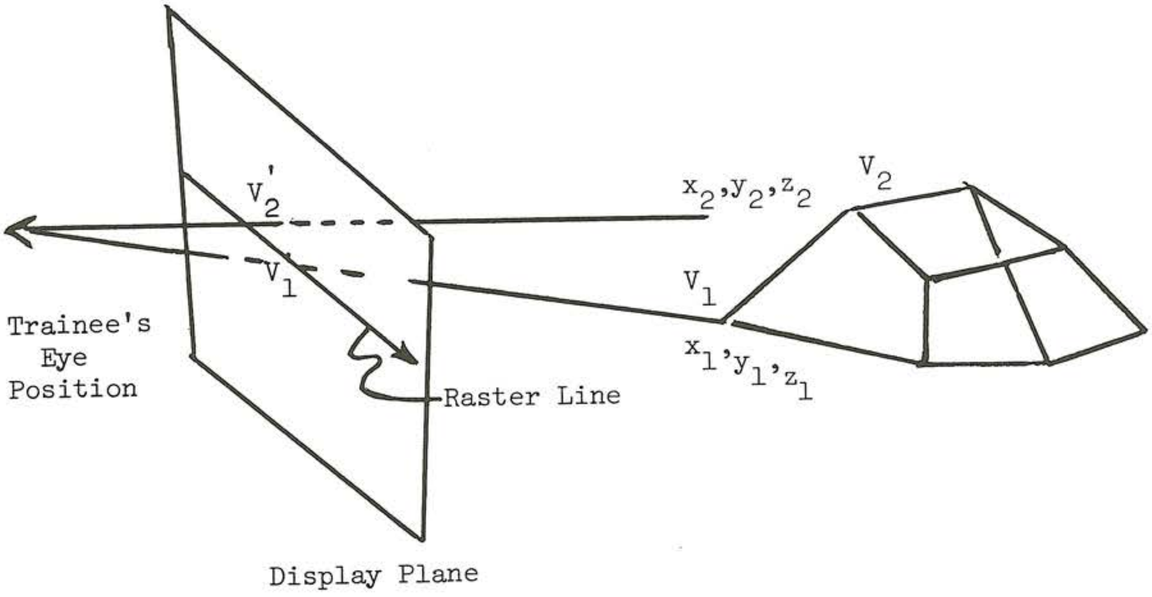

Figure 1. Principles of CGI System Operation

Each object in the mathematical environment is described by the x, y, and z coordinates of its corners, or vertices, in a fixed ground coordinate system. These coordinates can also be thought of as vectors from the origin of ground coordinates to the various vertices. The position of the trainee's eye point and the display plane, which corresponds to the screen of the display device, are tracked in real time by means of a dynamic vector which describes their position relative to the ground coordinate system. At the beginning of each television frame, the vectors from the eye point to all the environment vertices are found by adding in the eye point vector to each ground coordinate vertex vector. This set of vectors forms a valid description of the entire mathematical environment as seen from the trainee's point of view for the present television frame.

Given the set of vectors describing the scene, the CGI system first performs a perspective transformation from the three-dimensional mathematical environment into the two-dimensional display plane. This transformation is performed on each edge in the environment. (An edge is a straight line segment joining two vertices). The task remaining is to perform a scanning operation of the transformed edges in the display plane in synchronism with the television raster. At each instant in time, the system must determine which face of an environment object is visible through the point being drawn on the display plane at that instant. The color of the appropriate face is the color that should be presented on that raster element.

Several CGI systems are in operation at the present time. The first system capable of producing real-time scenes of three dimensional objects was installed at the NASA Manned Spacecraft Center in 1967. This system is capable of accommodating environments involving up to 240 edges and can drive up to three independent, full color views of the environment simultaneously. The 240 edge capacity is divided between the independent views when more than one view is used. Additional equipment will be delivered to NASA in 1971 to expand the capacity of this system to 500 edges.

Several organizations are presently using computer-generated image techniques for producing complex and realistic pictures in a slow time mode. A storage medium is used to accumulate the computed elements of the picture until an entire picture has been prepared, and the picture is then displayed. The basic principal is that of trading computing time for image complexity, sacrificing the ability to operate in real time. Many of the groups using these techniques are aiming their developments primarily at film making and computer graphic applications, without any intention of eventually producing real time simulation systems. Other organizations, however, use their slow-time systems as essentially non-real-time CGI systems for use in development of real time capabilities. Three such machines are installed at various General Electric Company locations, and Evans and Sutherland Computer Corporation at Salt Lake City, Utah, has been producing perspective scenes of very high quality and complexity for several years. The Evans and Sutherland work is performed in cooperation with the University of Utah.

These non-real-time CGI systems are not useful for simulation purposes since they cannot produce updated pictures fast enough to give the impression of motion through the environment. However, they provide a valuable means for evaluating advanced hardware concepts and for making movies by single frame techniques to allow assessment of subjective effects. They allow making CGI pictures with a small investment in hardware, and they allow their users to evaluate system concepts and algorithms without facing the many high-speed logic problems involved in implementing a real-time system.

A real-time CGI system is in operation at General Electric's Apollo and Ground Systems facility in Daytona Beach, Florida. This system has a capacity of 256 edges at the present time, and can drive one field of view. Effort is now underway to expand capacity to 500 edges and two view segments by the Fall of 1971.

Another CGI system is also now under construction at General Electric's Daytona Beach facility. This system will have a real time capacity of 500 edges, but it will be able to operate in an environment involving up to 2000 edges, with selection of the appropriate 500 edges for display being made on a real-time basis. This system will utilize three juxtaposed viewing channels, giving a field of view of approximately 180° horizontally by 60° vertically.

Since the introduction of the first CGI visual systems, certain limitations have conflicted with the application of CGI in a wide variety of training systems. Most of these limitations can be classified into two categories; image realism and cost.

Since the computing capacity required is a function of the number of edges in the environment, systems have traditionally had the capability of handling fewer edges than were really needed for satisfactorily real-looking scenes. Furthermore, the changing of displayed colors in synchronism with the main system clock leads to a quantization of data in the direction parallel to the raster lines. This leads to a stair-step effect which interfered with picture realism. Also, since the computations are performed for all objects, even if their display plane projection is smaller than a resolution element, scintillation and blinking on and off of distant small detail in the scene produces annoying results.

Developments in recent years have produced a significant progress in both picture quality and in system cost.

Systems having the capacity for handling 500 to 1000 edges can be produced with relative ease at present, and the capability for operating within an environment data base considerably exceeding the real-time edge capacity of the system has also been developed. This last capability has been pursued by many developers for considerable time, but developing efficient criteria for selecting the appropriate environment elements for display has made this goal difficult to achieve. Today, however, a hardware/software system has been developed which selects the correct environment elements in real time and uses a minimum of computational capacity.

Another recent development which complements the environment data base techniques described above is the capability for selecting one of several increasingly complex versions of each object to be displayed in the environment, in order to use only that edge capacity on each object which is required to present it to the level of detail that can be perceived.

Hardware has also been developed for providing limited visibility and weather effects. The illustration below (figure 2) shows the basic model used for producing weather effects. A layer of visibility-reducing medium is specified by the height of its bottom (h_b), the height of its top (h_t), and a quantity specifying the density of the medium (d). For each point in the displayed image, the range R through the medium is computed. The contrast ratio of the environment element seen through that point--in the case shown, the ground surface--is reduced as a function of the value of R. For the situation illustrated, the simulation would be of a situation having a layer of fog. The eye point could start above the layer, break into the layer, and then break out at the bottom.

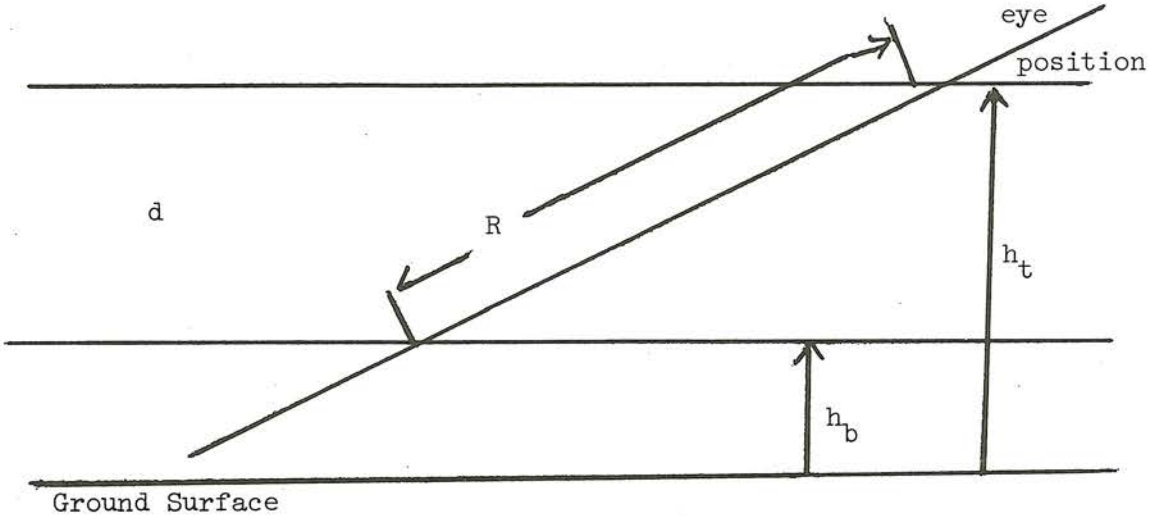

Figure 2. Basic Model for Producing Weather Effects

If the density (d) is made a function of altitude, effects of forming or dissipating fog can be simulated. If (d) also varies with North-South and East-West position, a simulation of clouds can be achieved.

Figure 3 shows a view of a runway with a simulated visibility range of 2,000 feet.

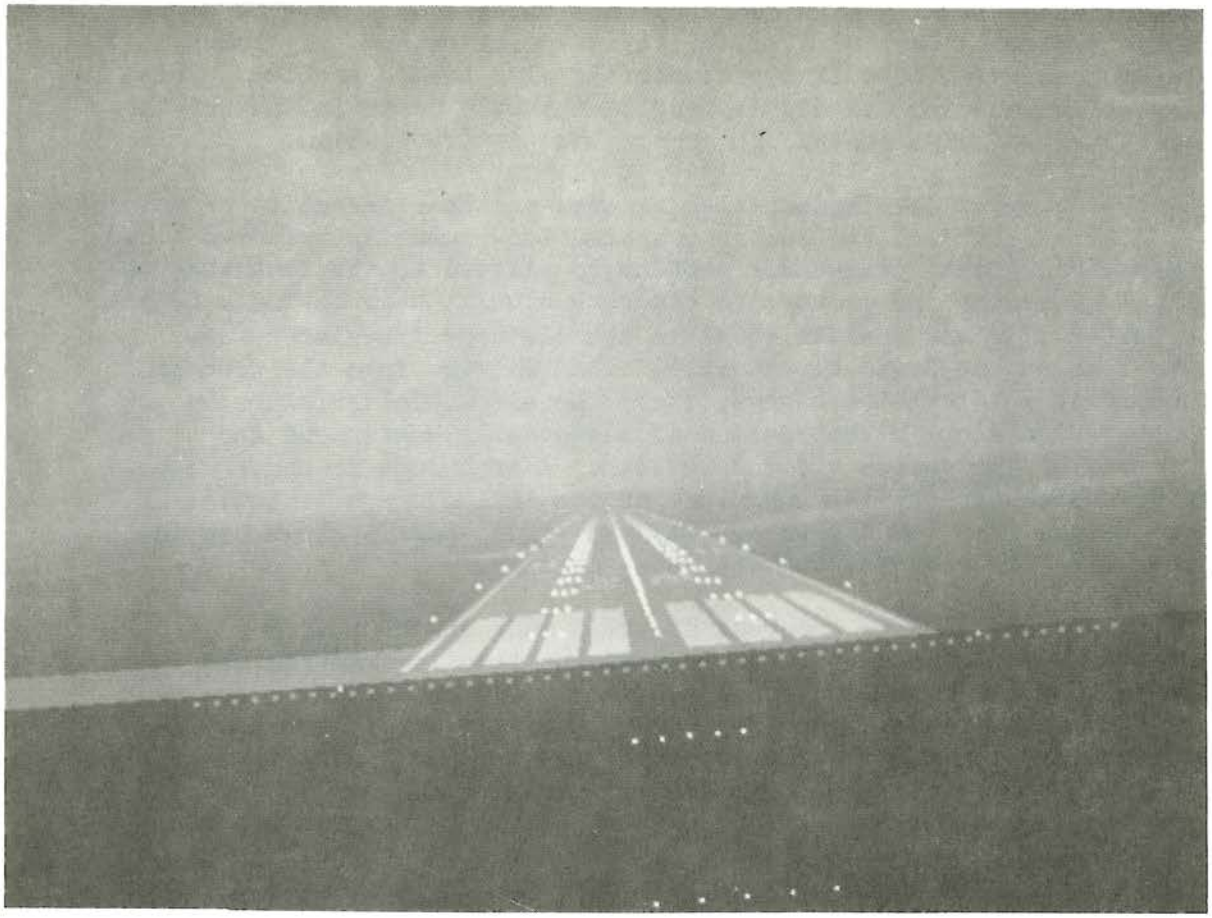

Figure 3. View of Simulated Runway

Another developed capability allows presentation of large number of lights, such as runway lights, with greatly reduced hardware complexity. Special features of lights, including effects of visibility-reducing media, effect of range on brightness, and directionality are also treated.

In order to take advantage of the inherent multiple view capability of CGI, a method has been developed for assigning environment objects to the view segments in which they appear, so that computations do not have to be duplicated for each segment in which the object might appear. In the system delivered to NASA in 1967, it is necessary to divide total edge capacity between the viewing segments. In the larger system under construction at General Electric in Daytona Beach, any of the edges can appear in any of the three view segments without deterioration of edge capacity. In addition, the view channel assignment hardware removes all edges which fall completely outside the field of view, with an attendant improvement in edge capacity. From the standpoint of improvements in cost, it is interesting to note that this system, despite its 2000 edge capability, costs considerably less than the 1967 NASA system.

Although many advances have been made in recent years, much advantage can be gained from developments now in process. One of these areas of effort is in increased resolution. Previous CGI systems have varied little from 525-line television standards. Picture resolution up to 1000 lines has been achieved on some of the non-real-time systems, but the problems of exceptionally high computational rates do not have to be faced with these systems. Lack of availability of color cathode ray tubes capable of presenting 1000 line pictures has also been a problem. Solution of the computation and display problems should occur in the not-too-distant future and will contribute greatly to picture realism.

Another current development area relates to the elimination of adverse effects that result from the raster quantization--commonly referred to as the stair-step effect. The basic problem is related to the fact that the CGI system generates the picture in discrete blocks, each having a height of one raster line and a width equal to the distance traveled by the electron beam in one basic clock cycle. This differs from the process that occurs in a television camera, where the allowable variation in brightness color along a raster line is essentially continuous and limited only by the system video bandwidth. A technique is under development now which essentially puts some of the analog characteristics of a camera system into the digitally computed video, and it shows considerable promise for reducing the stairstep problem.

Although considerable progress has been made in the system cost area, there is still much room for improvement to allow meeting the requirements of low cost simulation applications such as driver training. CGI visuals, if developed for sufficiently low cost, can provide interactive training for vehicle operators for testing and skill development. Currently, this type of visual for driving training is not available in any technology. Improvements in system architecture and product-oriented design show promise from bringing CGI visuals into the price category permitting their use for these applications within a few years.

COMPUTER-ASSISTED INSTRUCTION
(THE SFTS AS A COMPUTER-CONTROLLED TRAINING DEVICE)

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INTRODUCTION

I would like to open by giving credit to John Walsh who is now working for the General Counsel's Office of the FAA. John was primarily responsible for the conceptual development and implementation of Automated Training in the Link Synthetic Flight Training System, (SFTS).

THE SFTS AS A COMPUTER-CONTROLLED SYSTEM FOR TRAINING

Many training devices utilize computer driven equipment to provide training in tasks related to the operation of aircraft, locomotives, spacecraft or weapon systems in a total system called a simulator.

The SFTS is more than a simulator. It is a total training system which utilizes four UH-IH helicopter simulators as a part of the training system. The other parts of the system use feedback response from each of the four simulators to determine what the system should indicate to the instructor, the simulator, and the student(s).

The basic components of the system are:

- Four UH-IH cockpit simulators on motion bases
- Instructor's station controls
- Displays
- Aircraft sounds, taped messages for student exercises
- Computer complex for display system
- Computer complex for aircraft related systems and automated training.

Major functions of the total system are:

- To simulate UH-IH aircraft
- To respond to and control inputs to an instructor's station and student station
- To record information
- To control audio tape messages presenting training situations to the student
- To display student performance information
- To analyze and score student performance

This system faithfully simulates the UH-IH helicopter in terms of its associated systems, which include such things as airframe, power plant controls and indicators, and avionics equipment.

A complete instructor's station is capable of managing training in four cockpits simultaneously and of providing instructor/student communication, data displays (CRT's for student and instructor), data control, problem monitoring, training problem selection, malfunction control, closed circuit television control, flight recording control, and hardcopy device output control.

In addition to the capabilities mentioned, the device is capable of performing in two modes of operation, using different cockpits simultaneously. These modes are manual and automatic.

The manual mode need not be discussed because the automatic mode of operation is a derivation of the manual capability.

In a system that is completely controlled by a computer complex, the term AUTOMATED MODE of training, is an indication that the system is controlled by a computer and provides computer assisted instruction (CAI). This should become clear as we progress in the presentation.

COMPUTER-ASSISTED INSTRUCTION

Primarily, the function of the computer in a system such as this is to completely control all aspects of system operation. Since this is inherent to the system it implies the most important aspect of the system, that is, the COMPUTER is always aware of what is happening.

Since the computer recognizes student inputs it will react, during like training situations the same way time after time, regardless of who the student is. The computer never has a hangover from a night out.

In other words, the computer is in the system to assist instruction, because it is free from natural human weaknesses, it can anticipate actions, it will always respond in the same manner for every student for every training situation programmed into it. Actual flight situations can be duplicated and student execution monitored for comparison to established performance standards.

This brings up another important fact about COMPUTER-ASSISTED INSTRUCTION. The computer is a flexible instructor. It can be given new criteria to use, when scoring students, it can be given new methods to use in controlling the system, and it can be given partially or totally new training assignments without the need for a new device. This is accomplished by modifying existing computer programs and data (software), or developing additional software.

AUTOMATED INSTRUCTION IN THE SFTS

FUNCTIONS OF THE INSTRUCTOR'S STATION AND ASSOCIATED EQUIPMENT.

There are four functions which the computer performs for the SFTS while it is controlling the four cockpit simulators during automated training. These are:

1. Monitors and controls instructor station and associated equipment
2. Controls cockpit pilot training aids
3. Initiates information storage and retrieval
4. Selects and executes programs

The computer monitors the mode control switches, providing inputs to student monitoring devices at the instructor station such as: displays, selected student aircraft instruments, displays for ground tracing, altitude and vertical velocity plotting. Provisions exist for cueing and selecting appropriate devices for communications. In addition, the computer provides hardcopy printout, when the instructor requests it, for all cockpits. If the instructor wants to insert a training period or portion of a period for a student in a particular cockpit, he interrupts the actions for a selected cockpit. Through the use of a thumbwheel switch and pushbutton switches he can override anything that the computer is currently doing.

Malfunctions are programmed into selected problems. The instructor can prevent these from being automatically inserted by watching for displayed indications that it will be inserted and then inhibiting or removing the failure for the cockpit.

The instructor interacts with the system in the automated mode of operation. So does the student.

COCKPIT PILOT TRAINING AIDS.

The student has his normal cockpit instruments and controls. He can monitor his progress and the status of his trainer during certain phases of training by monitoring special student scoring and status indicator lamps. He can also monitor his own display unit to select training exercises, observe the map of his training area, and obtain information regarding his performance. Of course, the student can communicate with the instructor at his own discretion.

AUTOMATED TRAINING DESCRIPTION

All of these functions are going on during an automated training session. An automated training period is made up of the following:

- Briefing
- Demonstration
- Guided Practice
- Adaptive Practice
- Related Problem

A BRIEFING is automatically selected by the computer by cueing a particular selection on a tape to play through an audio system. The briefing will tell the student what to expect during the training period and tell him to start when he is ready.

During a DEMONSTRATION the cockpit is totally driven by the computer to do what the briefing has described.

When a GUIDED PRACTICE is in progress the student is permitted by the computer to operate selected control functions.

During an ADAPTIVE PRACTICE phase the student is permitted to control selected functions, but the computer inserts a selected parameter variation to increase level of difficulty in response to the student's performance. The adaptive variable is modified to make a task easier if the student has an error rate that is too great for the task being performed, or to make a task more difficult by increasing the effect of the variable if the student has a low error rate. When the computer acknowledges that the student has reached the end of an assigned task without reaching the maximum difficulty level as the result of his error rate being higher than that which is acceptable, the computer will automatically recycle the student through the task for more practice. If, however, the student reaches the minimum difficulty level when the computer is specifying further decreases in level of difficulty and the error rate is still too high, the computer will automatically stop all action so the instructor can intervene for consultation with the student. When the student has progressed to the highest level of difficulty for a task with acceptable error rates, the computer will proceed to "setup" for the next task. When a student is executing a problem during training he has complete control of the cockpit, but the computer is monitoring and scoring him throughout the problem, providing data to the system to be saved for instructor reference for critique and/or evaluation.

AUTOMATED TRAINING DATA

From the preceding statements it can be concluded that large quantities of data are being supplied to the computer to control the training program, sequencing of events and also for recording performance. The SFTS utilizes disc storage for this capability.

Automated training data is retained on the disc for use by the computer for training control. The computer also collects and organizes specific student performance data for output and later statistical analysis and review. This is accomplished simultaneously for each cockpit.

HOW THE COMPUTER ASSISTS INSTRUCTION

CONTROL FUNCTIONS.

The computer has stored in an internal memory complete sets of programs which provide:

- For monitoring and controlling all switches and lamps in the system
- For initialization of each cockpit to any one of nine training periods selectable by an instructor or student

- For information storage and retrieval
- For dispersing data to appropriate systems
- For selecting which programs should be executed and what the sequence is and when to execute.

The computer programs are controlled by a program called an EXECUTIVE. The function of the executive program is to control the WHEN and WHAT of a system of programs. When a cockpit is to be initialized, a particular program produces outputs, which set the device up, in a predetermined condition based on selected data retrieved from a particular disc file record. When this process is complete, the programs executed are those necessary for automated training. These are:

- Flight control
- Student performance measuring
- Automated demonstration
- Automated guided practice
- Automated adaptive practice
- Alert message control
- Displays control
- Automated malfunction selection
- Problem control
- Performance recording

and many more.

TRAINING FEATURES.

The features of the system, which are a result of the execution of these programs, are completely computer-controlled training periods

- Briefings, demonstration, guided practices, adaptive practice and problems
- Performance monitoring and recording
- Copilot relief
- Debriefing tapes
- Auto malfunctions and communication scripts for instructors

SUMMARY

PRESENT SYSTEM.

In brief, the SFTS system is a completely computer-controlled four cockpit training device. The instructor's role is one of interaction in the system only as an integral part of the system.

The computer has programs which are controlling a dynamic feedback response network. While the Computer programs are causing reactions to the outputs of each independent simulator, other programs are:

- Monitoring student and instructor setup requests
- Obtaining information from the disc file
- Putting data on the disc

- Monitoring student performance
- Selecting programs to be executed by the computer
- Controlling the display of information to both student and instructor
- Controlling the aural information presented to the student

It is important to remember that the computer has been programmed by humans. One must realize that the computer is merely an extension of the human brain, but it cannot learn. Its primary attributes are repeatability and programmability.

It is possible for the student to beat the system, that is, achieve a high score without performing in a prescribed manner. This is why the system has measures that are a reflection of performance criteria and do not simply correlate with them. Therefore, the computer truly assists the instructor by eliminating human subjective evaluations, when objective measures can be applied to each student, based on a prescribed set of training situations which each student must perform.

FUTURE COMPUTER ASSISTED INSTRUCTION.

The current Synthetic Flight Training System lends itself easily to future applications. In its present form, new and varied training exercises can be added to its automated training period repertoire by making adjustments and/or additions to input data. Also, as pilot requirements change or evaluation criteria change they can be readily incorporated into the existing system (programming) without the need of an entirely new device.

Automated training need not be restricted to aircraft alone, but can be used for nuclear and non-nuclear power plant operator training, ASW equipment operator training, or GCA flight controller training, just to name a very few.

Automated training techniques can be applied in any training situation that requires objective performance measurement, flexibility of criteria for evaluation, and the capability to apply new techniques to an existing device, or to a new device.

SAFETY ASPECTS IN AVIATION PHYSIOLOGICAL TRAINING DEVICES

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INTRODUCTION

This topic has been selected for discussion because of the rather unique problems associated with safety, when dealing with a group of devices, which we commonly refer to as Physiological Trainers. Safety, of course, is a subject that is written, shown, talked, and even preached about by virtually every segment of our society. However, in these trainers safety becomes the primary design criteria with all required hardware acting to support this one goal.

In this paper, it is intended to discuss this "safety as a design goal" by first briefly discussing Physiological Trainers and their training objectives, and then give a summary of a few of the more "notorious accidents" which bear directly on engineering design as applied or, in these instances, misapplied to physiological training environments.

PHYSIOLOGICAL TRAINERS AND THEIR TRAINING OBJECTIVES

Physiology, as defined in Webster's dictionary, is a branch of biology dealing with the processes, activities, and phenomena incidental to and characteristic of life or of living organisms. A physiological training device is, therefore, best described as a device associated with or causing the disorganization of physiological functions of a student. Aviation Physiological Training strives to teach the individual aviation-oriented student the "art," for lack of a better word, of survival when placed in an environment which is abnormal and potentially hazardous to him. In order to accomplish this a necessary part of the training must, in fact, cause a disorganization of physiological functions of the student. This is accomplished under controlled conditions, but unfortunately in some devices, in potentially hazardous personnel environments.

Typical of these devices are the Device 9U44 series, Dilbert Dunkers; Device 6EQ2 series, Ejection Seat Trainers; and probably the most complex and hazardous physiological device, the 9A/9U49 series, Low Pressure Chambers.

The training objective of the first of these devices, the Dilbert Dunker Ditching Trainer, is to train and expose a student to the methods and procedures required to escape from an aircraft which has somehow managed to become "water-borne" vice "air-borne"; that is, he has gotten his wings wet because he was over water and his propeller did not want to rotate any longer, or he got a "cold-cat" shot from the deck of a carrier in the case of a jet or propeller aircraft. In order to expose the student to this situation, we place him in a carriage at a height of approximately 25 feet mounted to rails which angle at approximately 40° to a water surface. The student is fully strapped into an operational aircraft seat after which the carriage, with student attached, is released. The ensuing events can best be described as the world's wildest roller coaster ride in that the carriage impacts the water at a considerable speed and almost immediately inverts and sinks to a depth which totally submerges the trainee. The trainee, at this point, finds himself upside down, firmly strapped and held by a number of belts and fittings to a seat, and submerged under water in a disoriented condition. His proper procedure is then to coolly and calmly release himself from the seat's restraining harness and swim out. Should he panic, and have to be extricated by safety divers, he has it all to look forward to again.

The second of these devices, the Ejection Seat Trainer, has the objective of training personnel to escape from an aircraft which, in its simplest sense, is anticipated to stop flying in the very immediate future. With the advent of relatively fast maneuverable and high altitude aircraft, which includes most post-World War II military aircraft, it is virtually impossible to open a canopy, climb out a cockpit and jump, thereafter opening a parachute. As a result, the ejection seat was invented and over the years considerably improved. The various ejection seat trainers we use are fitted with different operational ejection seats at various military stations, in such a manner, as to permit a Naval aviator to undergo ejection seat training on a seat identical to that used in the particular type aircraft he is flying. In order to accomplish this training the student is placed in an ejection seat, which is at rest, in a semi-enclosed area dimensionally similar to an aircraft cockpit. The seat is attached to a sled, which is mounted to rails, and is affixed at an angle of approximately 75° to the horizontal. The student is given the proper ejection sequence and body position and, thereafter, is told to fire the seat using the appropriate activation method. Upon student activation, a pyrotechnic charge is fired causing the sled, with seat and student affixed, to very rapidly travel up the rails to a height of approximately 10 to 12 feet.

The third of these devices, the High Altitude Low Pressure Chamber, has the objective of teaching the student or, in this instance, a group of students the use of high altitude life support equipment. This includes all the various types of personal oxygen supply masks and protective helmets as well as aircraft oxygen supply regulators as appropriate to the particular aircraft to be flown by the trainee. To the extent possible, the student uses his own personal issue survival equipment in the chamber, which serves the dual purpose of training the aviator, and gives him the assurance that the equipment will actually work, should he need it in his aircraft. Along with the operation of equipment, the trainee is extensively briefed on the physiological effects of high altitude or low atmospheric pressure on his body. Demonstrations are conducted to demonstrate hypoxia, which is a lack of oxygen to the bran and pressure breathing requiring the trainee to work to exhale, and a number of other rather insidious things, which a pilot may expect to be confronted with, when flying at altitudes above 10,000 feet without cabin pressurization. The device, in which this training occurs, is a rather substantially large compartmentalized steel rectangular box,which is attached by piping to a rather substantial vacuum pump. Through the use of controlling mechanisms, the pump is allowed to evacuate a compartment or compartments of the chamber which thereby places the student in a reduced atmospheric pressure environment identical to that experienced at high altitude.

In addition to the group training accomplished in all of the 9A/9U series Low Pressure Chambers, certain of these devices; specifically, the 9A9s and the 9U49B, have the capability of rapid or explosive decompression, which is used in conjunction with full pressure suit work. The full pressure suit is a rather complex garment which has the purpose of fully enclosing the human body and insuring that an atmospheric pressure is maintained on the body which sustains life (3.5 psia). This type suit has probably been seen by almost everyone in the world in that it was shown very impressively by Mr. Neil Armstrong on July 20, 1969, when he stepped on the surface of the moon. While Mr. Armstrong's suit was definitely of the very latest design it, in fact, served the same purpose as a military-type full pressure suit. In fact, if the life support back pack were removed from the NASA suit and the color was changed from white to our rather notorious olive drab, it would be difficult to distinguish an astronaut from an F-4 Phantom pilot, flying at 60,000 feet. Since all Naval aviators are required to wear this type suit, when operating at altitudes above 50,000 feet MSL, they must also be trained in the application, operation and mobility limiting factors resulting from its use.

The Decompression Chamber variety of Low Pressure Chambers is used for this type training. In this chamber there are three locks or compartments. The main compartment is approximately 18 feet long by 8 feet wide and 8 feet high. In a full pressure suit run this compartment is evacuated to a pressure equivalent to that at 100,000 feet MSL altitude (0.16 psia). The student, in his full pressure suit, is placed in the adjacent lock or compartment, which is called the intermediate lock. This lock is then evacuated to an equivalent pressure to that found at 35,000 feet MSL (3.47 psia). Then, by activating a large electro-pneumatically operated valve, air is allowed to pass from the intermediate compartment into the accumulator compartment. This action is rather impressive to watch since the end result is that the trainee, or more properly the full pressure suit, is exposed to a change in pressure equivalent to flying from 35,000 feet MSL (3.47 psia) to 65,000 feet MSL (0.74 psia) in something under three quarters of one second (the device is actually capable of performing this in 0.25 seconds). The effect on the student is that his suit "inflates" (actually the suit is maintaining existing 35,000 feet pressure and, since less air is around it, it appears to inflate), and the student meanwhile realizes that he has a mobility-restricting appurtenance around him. He will also probably note a beaker of water at approximately 98.6°F, which is placed in the chamber for demonstration purposes, boiling away as though the temperature has been raised to 213° F. This gives him a real appreciation of his full pressure suit, since he has been told, and now realizes that if his body were exposed to an altitude in excess of 62,000 feet MSL (0.89 psia), his blood would be boiling exactly like the water in the beaker.

This training, therefore, demonstrates the use, application and requirement for the full pressure suit in high altitude aircraft operations, since if an aircraft should lose cabin pressure at these altitudes, as a result of hostile action, failure of some cabin surface, or any number of reasons, there just would not be enough time to take remedial action. This incidentally, from all available information, is unfortunately an exact analogy of the situation the three Soyuz 11 Cosmonauts were exposed to in their fateful attempt to return to Earth after a completely successful orbiting space lab mission in late June of this year.

With this rather brief description of three of our physiology-type trainers, you can probably begin to appreciate the difference between a physiology device, and say, an operational flight and weapon system trainer (OF/WST). In the OF/WST the student is essentially taught to reason out and react appropriately as a result of audio-visual type information. In physiological aviation survival training you might say we go a little deeper. In the Dilbert Dunker we strap him in, run him down rails, flip him upside down, and put him under water; in the Ejection Seat we put an explosive charge under his rear, tell him to fire it, while reminding him that if he doesn't hold his back straight he could suffer a fractured spine; and in the Low Pressure Chamber we take his oxygen away and tell him he will not survive unless he uses his equipment properly. This then explains why physiology is different and also the extraordinary part safety must play in this type of device.

PHYSIOLOGICAL ENVIRONMENTS AND ACCIDENT HISTORY

From the preceding discussion, it would appear quite obvious that subjecting human beings to the "exhilerating experiences" of a physiological device must, by necessity, sooner or later result in an injury and, in fact, a good argument can be made for this position. On the other hand, the student or trainee is at a point in life when he could readily be considered in ideal physical condition. The average trainee has been pumped full of health-assuring vaccines, examined from head to foot, has no heart, liver, lung or kidney problems, and probably cannot even exhibit a decent hemorrhoid. The fact is, that, the trainee is probably at the peak of physical condition and at an age where his body can withstand punishment and abuse better than at any time in his life.

What, then, is the reason that accidents happen in a physiological training environment? My experience, over the past nine years, has been that one factor always stands out in every accident. This factor is the total underestimation of the crossing of sciences and fields of technology involved in design, fabrication, maintenance, and utilization of any of the physiological training devices. After all, these devices certainly do not appear to have nearly the complexity of any self-respecting computer. The truth of this situation is, however, quite different. While the computer designer must have an excellent knowledge of state-of-the-art electrical engineering, the engineer working in physiology has almost daily need for, at least, a basic knowledge of electrical engineering, mechanical and structural engineering, including hydraulics and pneumatics, chemistry, physics and in the case of altitude chambers, high altitude physics. Then, to further complicate the situation he must understand how each of these fields affects a living organism. The effect on living organisms is, needless to say, the worst stickler in this requirement. Unfortunately, the engineer or technically oriented man tends to "think at right angles" to the physiologist or medical individual. As a result, a lack of communication is quickly established and the two go their separate ways with no follow-up on the part of the engineer. The engineer complains that no one appreciates his technological breakthrough and the user, in this case the physiologist, thinks it is not esthetically pleasing and something is wrong, but he does not know how to explain it. Meanwhile, the engineer does not follow-up on the device's operation or utilization since he will not be appreciated. Then "bingo" a disaster occurs. This cycle seemingly occurs over and over again to the consternation of everyone, especially the accident victim. That is to say, the one truth in this rather unusual training device field is "Murphy's Law" (anything that can go wrong will go wrong) will prevail.

As an example, take the case of the gentleman who is now considered the father of aviation physiology. During the early 1800's he was concerned with the physiological aspects of high altitudes on living organisms. Not being certain what would happen to a human, ascending from the surface of the earth, he wisely chose one goat and one duck to be put into a gondola below a hot air balloon. The balloon was released and subsequently ascended with the goat and duck. An hour or so later the balloon descended back to earth and the goat was found to be in excellent condition, thereby, proving that a living animal and, in all probability, a human could exist at what was then considered a high altitude. Unfortunately, however, the thought of restraining the goat within the gondola had not been properly considered and the goat had, in fact, not appreciated the experience of being the first goat in free flight. As a result, while the experiment was in all aspects a scientific success, the duck was found dead in the gondola, trampled to death by the goat and, thereby, proving conclusively that "Murphy's Law" existed before the twentieth century, at least for ducks. Since that time there have been a number of similar situations in a physiology training or physiology environment. Some are comical, but unfortunately, many are sad.

On the Device 6EQ2 Ejection Seat Trainer a situation occurred where a young Naval aviator, an Ensign, found that the ejection seat went further up the rails than anticipated. In fact, the seat went all the way to the top of the rails and was teetering back and forth in the breeze balanced precariously by only two of its four restraining mechanisms. Fortunately, the Ensign had a strong heart and no injury resulted. The cause of the incident was probably too much black powder in the cartridge used in an overheated barrel assembly on a very hot day. Shortly, thereafter, a modification was made to the ejection seat firing barrels employing a relief port, which activated if overpressure from a charge occurred. In the 1960's, a number of accidents have occurred on ejection seat trainers, such as broken toes, when a student's foot hit the simulated instrument panel of the cockpit section of the trainer as the seat moved up the rails, or bruised elbows, when the student's arms hit the side of the cockpit. We even had a barrel assembly explode at a Naval Air Station in our own state of Florida. In each instance,modifications were quickly made and fortunately only one man was seriously injured.

On the Dilbert Dunker, no injury of any consequence is known to have occurred until early last year when we were informed that a Marine pilot at a Marine Corps Air Station sustained fractures of the 6th and 7th cervical vertebra, as well as a badly cut mouth. The history of this accident is a typical "Murphy's Law" situation. In other words, a long series of circumstances just waiting for an accident to happen. The device had been in operation for many years without any apparent problem. At the time, the device had not received any type of quality assurance and inspection, and because of its long history of good operation, had not received any priority for an inspection. The Marines, by their very nature of being good fighting men, did not really have their hearts in water survival training and consequently did not properly perform even routine maintenance on the device. They also had determined that the inertia reel on the ejection seat was too much trouble to pull against each time a student was strapped into the device. As a result, they had pulled the seat shoulder straps out and locked the inertia reel by wedging something in the teeth of the reel. This of course allowed the student to move his upper torso freely in the seat, since his shoulder straps no longer restrained him back into the seat. In addition to this, the two catch assemblies, which are supposed to prevent the cockpit from inverting until being released just before reaching the water, were in such condition that one catch was totally inoperative, and the other so rusty that the Marines admitted having to jump up and down on the cockpit to make it engage, when the carriage was retrieved back to the top of the rails after a ditching run. Add to this a particular day when the usual operating crew were not available and a new crew took over. The result was that the cockpit was not locked down in the carriage, when the student got into the device. After strapping the student in, the carriage was released and almost immediately started to invert. At this point the cable drum operator slammed on the brake abruptly stopping the cable drum, cable and cockpit carriage. This naturally gave the cockpit, which incidentally had reached approximately 90° of its full 180° inverted position, a tremendous jerk, thereby, giving the student what can only be called one of the most confirmed cases of whip lash in history. In this accident everyone was actually lucky. Why lucky? Because if the carriage had continued down the rails in the inverted position, the major part of the cockpit would have cleared the edge of the pool and, along with the section of the student's body from the neck down, gone into the water. But the top of the seat, and from the neck up, the student would have stayed on dry land. Needless to say, immediate "Murphy" proof modifications were initiated and a quality assurance inspection procedure was established. Since that time, several additional safety oriented, but unrelated modifications have been made on this series of devices.

The 9A/9U49 series of Low Pressure Chambers, in the area of safety, present by far the greatest challenge of any physiology training device. To date, we in the Naval aviator training have been extremely fortunate. We have not experienced a single known serious accident in any low pressure training chamber. It might be added, in retrospect, that knowing the scope and purpose of numerous modifications, directives, and procedures, which have been instituted since 1965, would amaze any rational person in that "Murphy's Law" never caused a group fatality in one of these devices. Unfortunately, our counterparts in both NASA and the Air Force were not that lucky. The NASA incident occurred on January 27, 1967, when LCOL Virgil I. Grisom, LCOL Edward H. White II, and LCDR Roger B. Chaffee were burned alive in a physiology environment, resulting from a flash fire aboard Apollo I, during a launch pad test. This fire was ultimately attributed to electrical arcing in a wiring harness within the capsule. Just four days later, on January 31, 1967, at Brooks Air Force Base, Texas, two airmen met a similar fate. In order to better appreciate the hazards of a fire in a closed compartment, housing personnel in an altitude simulating physiological environment, and specifically in these cases, as in our chambers, an oxygen enriched atmosphere, let me briefly go over the situation that occurred at Brooks.

At about 8:18 AM, on the morning of January 31, 1967, two airmen entered a low pressure chamber for the purpose of conducting tests in the chamber, at an equivalent pressure of 18,000 feet MSL (7.3 psia), in a high oxygen content environment. After about twenty minutes the outer lock in which they were standing had reached the 18,000 foot altitude,and the door was opened between the outer lock and adjacent main lock, which was already at 18,000 feet. The two airmen then entered the main lock to attend to some animals on which the testing was being performed. A few minutes later the crew chief, who was sitting at an instrument panel outside, heard a noise,which to him sounded like an animal cage being dropped inside. He then went to a porthole where he saw fire in the chamber. Immediately, he sounded an alarm and the fire department arrived in two minutes, and two doctors were ready to give aid in approximately two and a half minutes. However, the firemen and doctors were all to no avail. The casualty list--sixteen rabbits, about fifty mice, and two young airmen.

The resulting investigation indicated that the fire had probably been started by one of the airmen stepping on a teflon covered power cord attached to a goose neck lamp which was plugged into a standard 110 vac utility outlet inside the chamber. As a result of stepping on the cord, the cord shorted to the steel to the steel deck with the arc igniting the bottom of the airman's trousers. Experiments have shown that once ignited the airman would have been completely engulfed in flame in a matter of mili-seconds and, assuming combustible materials within the chamber, the entire chamber would have been engulfed in flame within two seconds. What went wrong? In my opinion, somewhere there are some engineers and technicians now spending some sleepless nights because they installed 110 vac utility outlets in a chamber housing combustible materials totally neglecting "Murphy's Law." Truly—an accident waiting to happen.

CONCLUSION — A CHALLENGE OF SAFETY

In conclusion, I would like to summarize this topic by saying--physiological training devices and physiological training environments are different. We deal directly with the human body—not just with replaceable hardware. I would also like to give you the following six tenets of "Murphy's Law":

1. IN ANY FIELD OF SCIENTIFIC ENDEAVOR, ANYTHING THAT CAN GO WRONG, WILL GO WRONG.

2. LEFT TO THEMSELVES, THINGS ALWAYS GO FROM BAD TO WORSE.
3. IF THERE IS A POSSIBILITY OF SEVERAL THINGS GOING WRONG, THE ONE THAT WILL GO WRONG, IS THE ONE THAT WILL DO THE MOST DAMAGE.
4. NATURE ALWAYS SIDES WITH THE HIDDEN FLAW.
5. MOTHER NATURE IS A BITCH.
6. IF EVERYTHING SEEMS TO BE GOING WELL, YOU HAVE OBVIOUSLY OVERLOOKED SOMETHING.

Finally, I would plead with you, that when dealing with Physiological Training Devices, always "THINK MURPHY".

SESSION VI

Thursday, 17 February 1972

Chairman: Mr. Harold Rosenblum
Deputy Director of Engineering
Naval Training Device Center

AUTOMATED GCA-FINAL APPROACH TRAINING

DR. J. P. CHARLES AND MR. R. M. JOHNSON
LOGICON, INC.

Recognizing that recent results from training research and development programs as well as from advanced digital technology could contribute to the solution of training problems, the NAVTRADEVCEN in 1969 initiated a program to test the feasibility of implementing some of these advances.

As part of this effort, LOGICON, INC. analyzed the feasibility of automating portions of weapon system trainers (WST) and prepared some design guides to illustrate implementation on selected flight profile segments. The F-4 trainer was chosen as a sample case. The initial effort involved a survey of typical trainers in operational use. This review of on-going training utilizing WST's concluded that in large:

- WST's were being used primarily for cockpit orientation and procedures training.
- There was a lack of a well-defined approach for utilizing WST's.
- There was a lack of performance criteria and measurement.
- The instructor's role was not well-defined and their approach to training varied widely, especially in student evaluation.

The study indicated that the major technical problems in automated training involve:

- The development of computer programs to evaluate student performance and restructure the training course in real-time.
- The implementation of computer control of all training steps and functions.

The next effort undertaken, by LOGICON, INC. was to demonstrate technical feasibility, the problem being stated as one of implementing sufficient automated weapon system training to demonstrate technical feasibility in terms of computer programs and crew station development, within realistic and practical constraints.

The initial task involving a review of feasible simulators for the test, resulted in the selection of the Training Device Computing System (TRADEC System) at the Naval Training Device Center. This system, which was designed for Research and Development efforts, has the flexibility required for experimental tasks, and most importantly, could be modified and scheduled relatively easily.

Once the TRADEC System had been selected, the training task was bounded in scope and content. The TRADEC System includes a simulated single seat fighter type aircraft. The F-4 aerodynamic equations are utilized. Figure 1, is a block diagram of the major subsystems. The ones of particular interest include the motion system and the COGNITRONICS speechmaker. The latter device assembles a fixed vocabulary into phrases and sentences under computer control. The motion system is driven by the F-4 program contained in the computer. Thus, the TRADEC System constrained the training task to a basic fighter aircraft task with oral command capability. Instrument flight would be required since visual projection equipment is not installed.

A review of the flight segments analyzed in the earlier LOGICON study clearly indicated that the Ground Controlled Approach (GCA) was the most logical task to employ since:

- The task requires an elementary cockpit; i.e., no navigation or flight director system.
- The task is performed under instrument flight conditions.
- The task is a common operational task of fighter aircraft and is of relatively short duration.

The COGNITRONICS Multiplex Speechmaker provided the solution to the GCA voice command input requirement.

Emergency procedures, compatible with the GCA, were selected for additional demonstration tasks. A review of F-4 aircraft emergencies resulted in the selection of two: (1) single engine failure; and, (2) communication failure as feasible for implementation and compatible with the GCA task.

Potential student populations were reviewed. The requirements for a reasonable testing period and meaningful results for weapon system training for operational application dictated the use of qualified military pilots as the primary group.

An analysis of the GCA task was conducted to identify the performance criteria, performance measures, task structure, typical operational environment, and task difficulty factors. For example, standard terminology was collected and tapes of actual F-4 GCA's were recorded and reviewed. Handbooks on the F-4 and GCA Systems, including the SPN-35 and SPN-42 systems, were studied.

The complete GCA includes both a vectoring mode (Airport Surveillance Radar (ASR)) and a precision approach mode (Precision Approach Radar (PAR)). It soon became clear that the vector mode, although not technically difficult to mechanize, would involve extensive modification to the F-4 software. Therefore, the final approach phase, PAR, was isolated for the flight task.

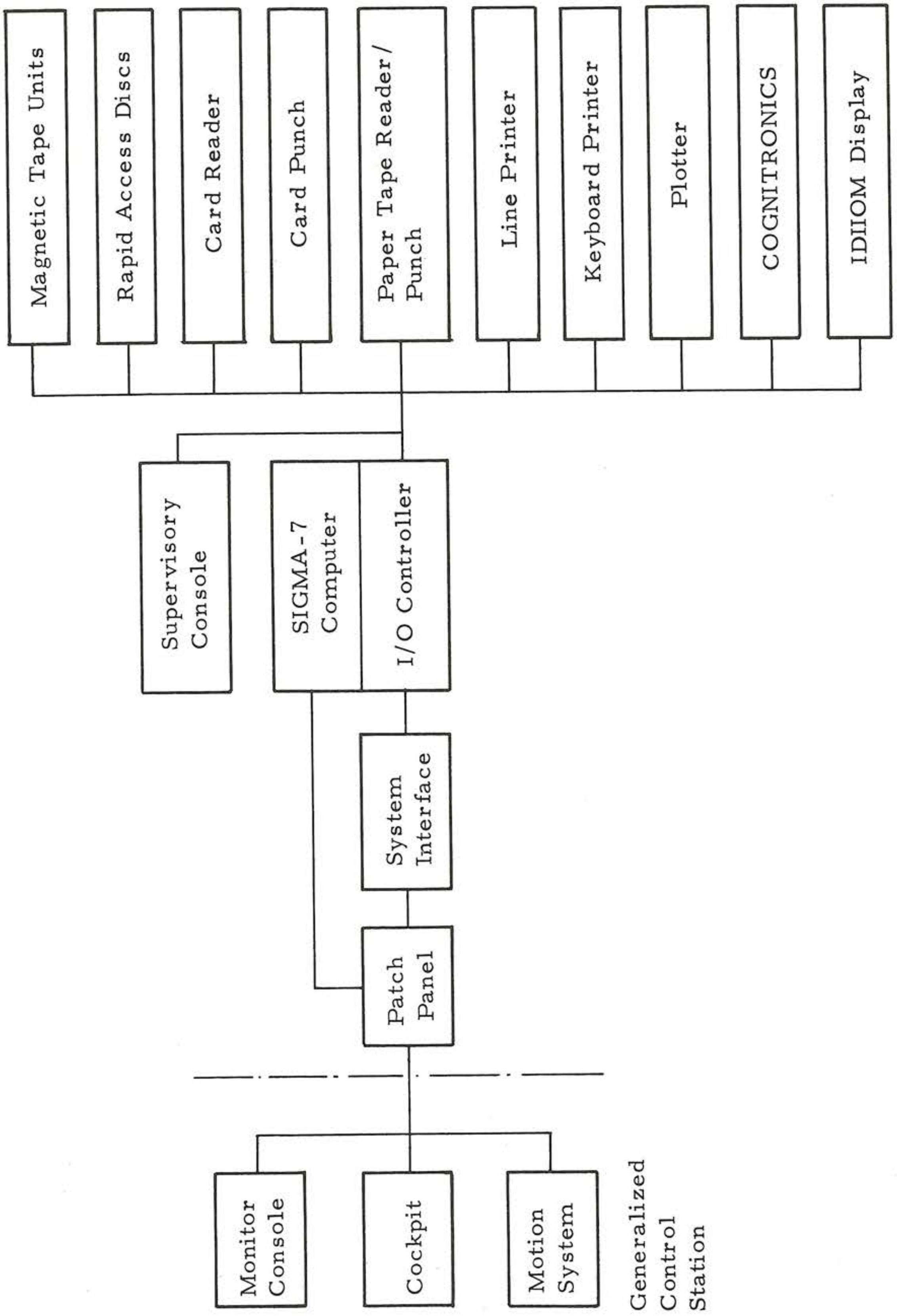


Figure 1. TRADEC System

Functional descriptions provided the foundation for the design and development of the computer program and training program. The end product was a design package which was used to implement the demonstration program. It included:

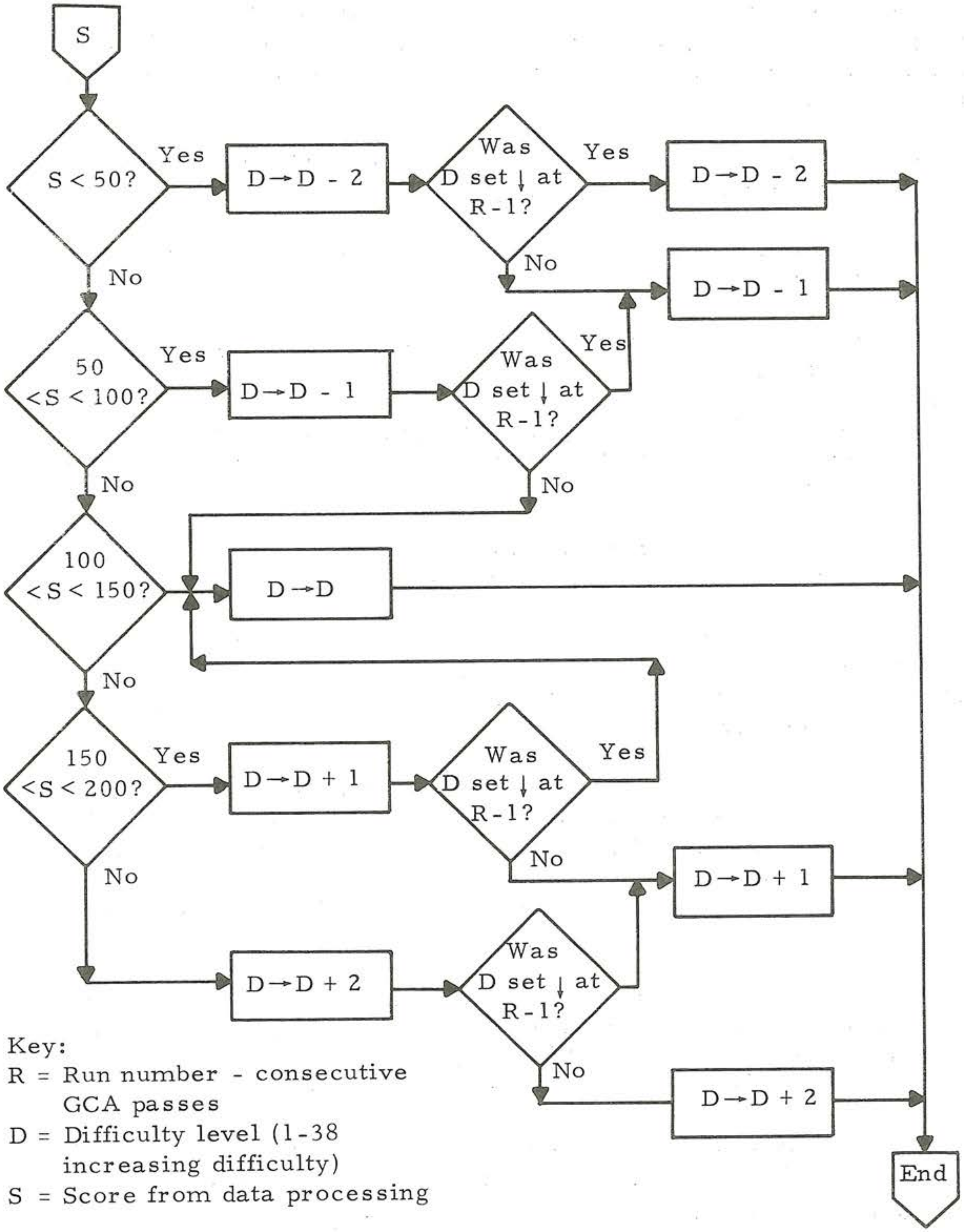
- A detailed description of the test to be performed to demonstrate the automated training techniques.
- The design and development of the software required for the demonstration.
- Preparation of training schedules, data forms, and student briefing lectures.
- Specification of the required changes to the existing TRADEC hardware/software to properly interface the proposed demonstration program.
- The design of a test plan to adequately check out both the experimental concepts and the program itself.

Three design tasks were conducted. The first involved the development of a sequence of GCA's of increasing difficulty; the second involved design of a system for scheduling the GCA; and the third involved development of a measurement system.

A training course consisting of 38 different runs for GCA training and five for emergency procedures was designed. The analysis of the GCA requirements had produced three major task difficulty factors. These were changes in aircraft weight and drag, atmospheric turbulence, and runway wind conditions. Five conditions and levels for each factor were selected. All reflected F-4 operational capability.

An adaptive logic program was developed to permit the student to complete the course in accordance with his ability. Figure 1 is a flow diagram of the logic developed. The procedure is actually "adaptive-adaptive" since a series of successful runs can accelerate the schedule.

A variety of performance measurements were investigated ranging from control stick displacements and rates to vehicle angles and rates to GCA errors. As discussed earlier, interpretation becomes difficult for all but direct system performance measures. Fortunately, the GCA has very definitive performance requirements. Therefore, measures related to operational performance were feasible. Two separate scores were developed. The first reflected performance during the run. The second reflected offset position relative to the runway at the conclusion of the control phase of the PAR.



Key:
R = Run number - consecutive GCA passes
D = Difficulty level (1-38 increasing difficulty)
S = Score from data processing

Figure 2. Adaptive Logic Flow Chart

Approach path performance was measured in terms of position error and angle of attack at a one second rate while on final approach. Final performance was measured in terms of actual position with respect to the glide path at the time of passing through final "gate". Five measures were taken:

1. Lateral displacement in feet from the approach course centerline.
2. Vertical displacement in feet from the glide slope centerline.
3. Angle of attack error in units from optimum.
4. Rate of heading change in degrees per second.
5. Rate of angle of attack change in units per second.

These measures resulted in 15 path measures and 5 gate measures. These were combined to provide a single score for input to the adaptive scheduling plan. In effect, a path score was computed for all runs. If successful, a gate score was computed and the path and gate scores were combined for a total run score. If the run terminated in a wave-off or a crash, the path score was adjusted to compensate for the proportion of the run completed.

The original constraints imposed on software design reflected the requirement for compatibility with the F-4 simulation program, especially in cycle time, and with the TRADEC System capability in general. Since the time remaining in the computation cycle was limited, it became clear that an executive program would be essential and that a modular approach to the program would be optimum. The executive program was required to monitor and control execution of the modules and provide the interface with the existing TRADEC software. Other functions of the executive program included:

- Monitor inputs
- Direct outputs and feedback parameters
- Control communications between modules
- Transmit data between operator and program
- Schedule events
- Establish priorities
- Allocate memory for the modules
- Provide procedures for error recovery
- Provide timing and accounting parameters.

The basic design of the executive program involved a foreground and background mode. The advantages of this design included:

- Program modules were list ordered by execution priority.
- The Executive Routines were independent of the other modules.
- Priority of any Foregound or Background (F/B) program was easily changed by reordering the program lists.
- Active modules could activate or deactivate any other F/B program.
- Inactive modules were easily bypassed.
- New modules were added by simply inserting the program and a one-word linkage to the list.
- Obsolete modules were removed by simply removing the program module and the one-word linkage.
- Modules could be virtually removed by deleting the one-word linkage.
- Foregound modules could be transferred to Background (and vice versa) by interchange of the one-word linkage.

These features are obviously desirable for an advanced program where flexibility is essential. Figure 3 illustrates the basic hardware/software system flow.

A total of 12 Navy and Air Force F-4 pilots were "trained" during the test phase. Additional data on two nonpilots was accomulated for comparison.

All of the 12 F-4 pilots were on operational flight status with an F-4 squadron. The pilots were only available for one day because of operational and training commitments. Therefore, the training plan was a "pilot-demand" schedule in which the pilots flew GCA runs until they were tired or wanted to rest. Two pilots were scheduled per day so that they could alternate flying and resting. Training began about 0900 and continued as late as the pilots were willing to fly or until they completed the course. This procedure resulted in a median number of trials per session of seven.

Five of the 12 pilots completed the GCA course in terms of reaching the most difficult level of the syllabus. The median number of runs for these pilots was 26 as opposed to a median of 30 for the pilots, who did not complete the course, because of time limitations or fatigue.

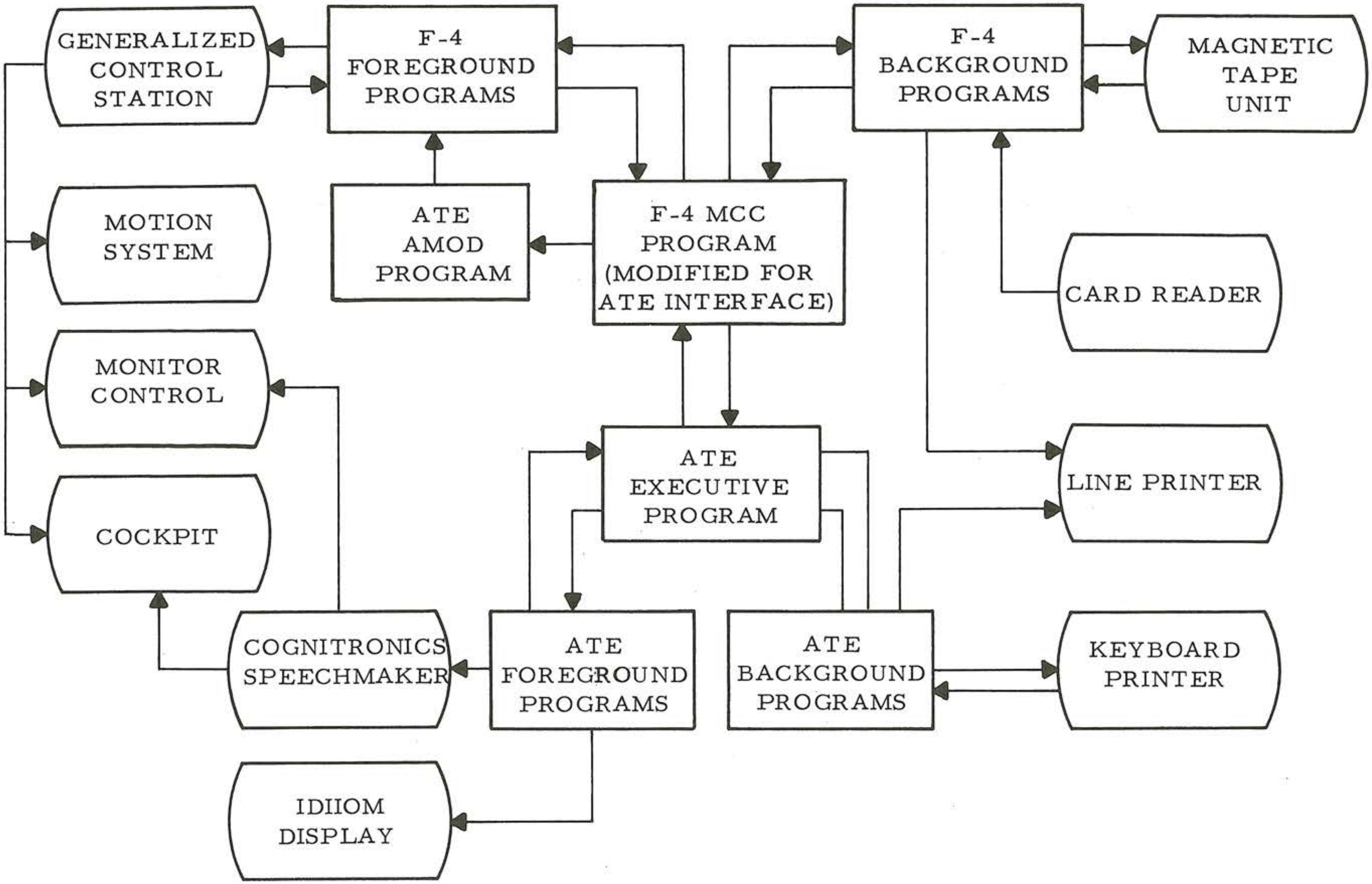


Figure 3. F-4/ATE Basic Hardware/Software Systems

Plots of the progress of each pilot as a function of the run number and difficulty level reached were made. Figure 4 is a sample plot.

It was concluded that the technical feasibility of the concept of automated instruction in a weapons system trainer has been demonstrated and that the state-of-the-art of digital systems and training methodology appears adequate for implementation of automated training.

Based on the limited nature of the tests concluded, the following additional conclusions are suggested:

- Automated flight training is acceptable to pilots.
- Adaptive training techniques can be implemented and appear effective and acceptable by the students.
- Voice generation techniques are adequate for simulation purposes.
- Pragmatic solutions to student performance measurement are feasible and prove useful for training control. Total system performance criteria, however, must still be established and measured.

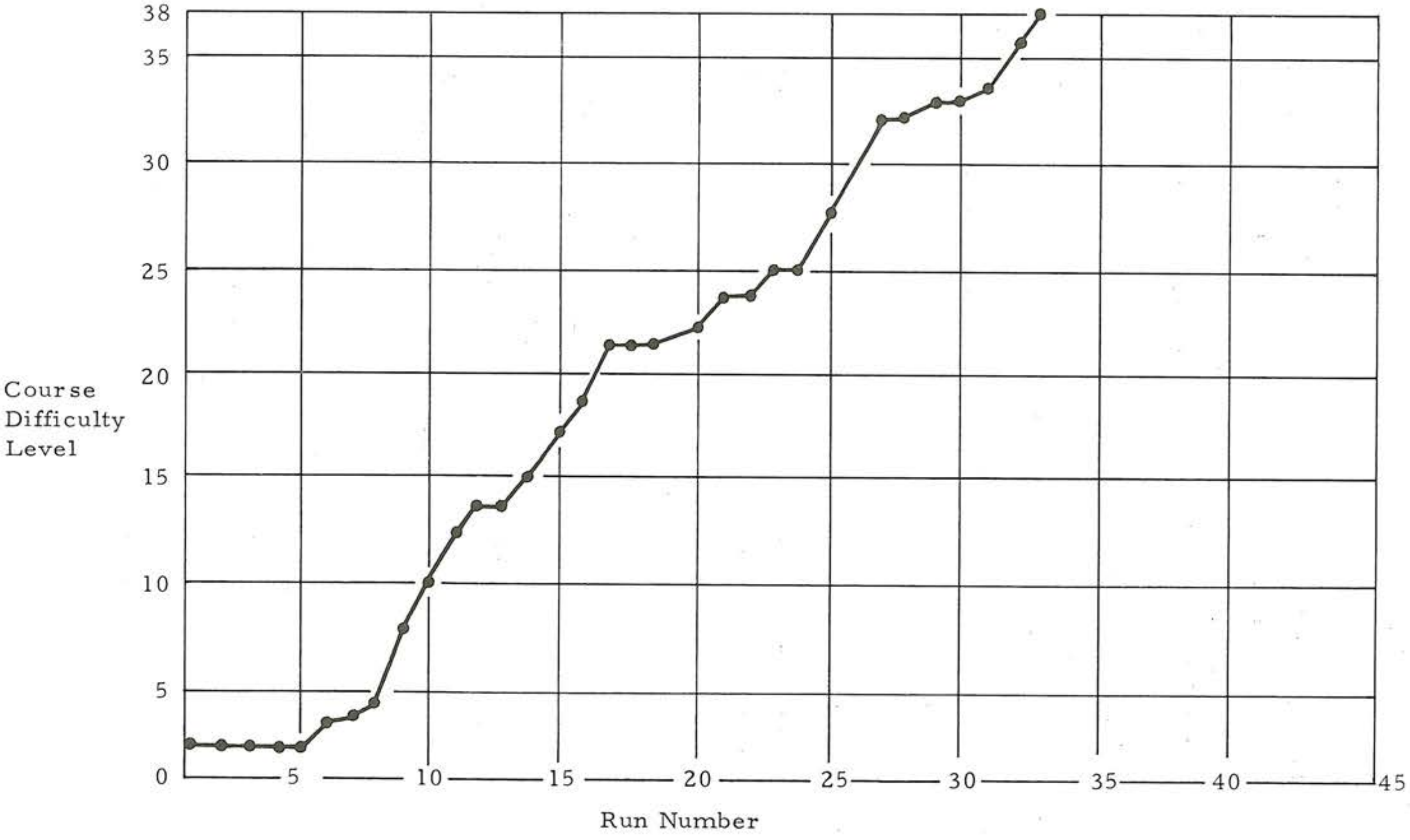


Figure 4. Sample Pilot Data

PAPERS PUBLISHED
BUT
NOT PRESENTED

ROLE OF DIGITAL COMPUTER MODELS IN TRAINING DEVICE DESIGN AND PERFORMANCE MEASURES

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The need to evaluate student and instructor workload with more precision during training device design increases with the cost and complexity of new systems. Paper and pencil methods are adequate to evaluate total student and instructor workload early in the design, but have weaknesses when applied to task distributions, probability effects, and simultaneous events. Computer methods have been developed to give equipment designers early quantitative data on student and instructor workload capability (Asiala, 1969; Chubb et al, 1970; Clausen et al, 1968; Nelson and Jackson, 1968: Siegel and Wolf, 1969; and Topmiller, 1968). This paper describes a model which provides more realistic student and instructor workload data. The model has these advantages compared to other available models in that it:

- Provides required core independent of the number of requested replications
- Supplies visual, right and left hand, feet, communication, and auditory and visual information processing loadings besides the total task loading
- Considers simultaneous tasks
- Provides task distribution
- Simulates human failure rates and learning curve variations.

Analytical and computer techniques are combined in the model to aid in determining student and instructor display and control requirements, station configurations, and allocation of tasks. In addition, it provides the effect of automated and manual operations on task loading, queuing delays and reliability, the impact of diverse add-on requirements, and the performance measurement criteria.

BACKGROUND

Monte Carlo simulation is a useful technique for improving decisions about military systems and operations. With increasing system complexity, simulation is essential for understanding system elements and their interactions. Some large, complex training systems cannot be examined directly because:

- Proposed system in development phase such as the F-14, F-15, and Harpoon
- Experimentation with real system difficult and costly
- Experimentation involves risk to human life such as high g's and radiation.

The Siegel-Wolf (1969) and other models have some limitations for weapon system applications as we discovered on our F-14 and F-15 early design studies. The McDonnell Douglas Corporation (MDC) Pilot Simulation Model (Asiala, 1969) eliminates these limitations. Our Advanced Multi-Man Crew Digital Simulation Model is an extension of this MDC Pilot Simulation Model FORTRAN program. It is generalized to the extent that it can be used to model virtually any instructors/students activity network.

Specifically, we have a stochastic digital model with variable and parallel flow logic to simulate multi-man workload. Input and output data procedures are described in sufficient detail for direct application to student/instructor interfaces. The simulation model is programmed on the IBM S/360 computer and utilizes the PL/1 language (Pollack and Sterling, 1969; IBM, GC28-8201 and -6594). PL/1 was chosen as the language because it possesses the power and flexibility required to implement simulation models of large and complex systems, and it allows dynamic storage allocation and pointer-connected set manipulation, which are necessary mechanisms for efficiently implementing event-oriented simulation models.

Since this simulation model has parallel flow capability, the training task logic varies the sequence of tasks for the instructors and students. This variation is controlled by the probabilities associated with the training task or event logic. Each new training task logic is established by the input cards without revising the integral parts of the program. The model has these properties:

- System independence
- Ease of formulation and change
- Minimum requirements of system assumptions
- Static and dynamic system performance information .

MODEL

The two most widely used programming languages for event-oriented simulation models are GPSS (IBM, 20-0304) and SIMSCRIPT (Markowitz, 1969). Experience gained through using both languages has shown that GPSS is an excellent language for small simulation studies, where the primary concern is the minimization of the manhours required for programming. However, GPSS does not possess the flexibility and efficiency required for constructing models of large, complex systems. Whenever language flexibility is required and whenever a concern exists regarding run time and storage requirements, than a more powerful language, such as SIMSCRIPT, is more suitable than GPSS. The complexity of a multi-man crew simulation model requires the use of a highly flexible language such as SIMSCRIPT. However, early SIMSCRIPT compilers were unreliable. Recent versions are reliable but costly. The solution to this problem is to use another language with SIMSCRIPT flexibility but also including mechanisms for efficiently implementing simulation models. The best mechanisms are pointer-connected set manipulation and dynamic storage allocation. One approach, used on F-15 Pilot Simulation Model (Asiala, 1969), is to use FORTRAN with Douglas SIMSYS package of subroutines (Brinsley, 1967). PL/1 is another suitable language and was utilized for our Multi-Man Model because it was more efficient than a FORTRAN program in terms of run time, and SIMSYS dynamic storage allocation technique restricted the size of storage pool to 43,000 words, a severe limitation for large models.

Model Subroutines - The primary routines are MAIN, INPUT, STRTREP, EVENT AND REPORT. MAIN controls the simulation by calling EVENT routines and updating simulation clock. INPUT reads in and checks user supplier input data and creates block entities. STRTREP begins a replication. When an event notice is removed from the calendar, the EVENT routine is activated by MAIN routine. EVENT also creates event notices for block output 1, through predecessors. REPORT summarizes statistics at end of run and produces user-requested reports, and generates a plot tape for the CALCOMP plotter.

The nine secondary-service routines are:

1. START - Creates an event notice and places it on the calendar and is called by EVENT and STRTREP.
2. FIL-FST - Files an entity at the beginning of a pointer-connected set.
3. FIL-LST - Files an entity at the end of a pointer-connected set.
4. FIL-RNK - Files an entity into a ranked pointer-connected set.
5. RMV-FST - Removes the first entity in a pointer-connected set and returns its pointer.
6. RMV-LST - Removes the last entity in a pointer-connected set and returns its pointer.
7. RMV-SPC - Removes from the set if entity is a member of a pointer-connected set.
8. CAUSE - Files an event notice entity into the calendar.
9. CANCEL - Removes a member event notice entity from the calendar.

Simulation Model Operational Procedures - The operational or training network consists of one or more connected sets of blocks. A block consists of a set of task elements performed by a crewmember, student or instructor. Based on our FORTRAN simulation model experience, the block structure illustrated in figure 1.was developed for our Multi-Man Model. This block structure consists of time delays 1 and 2, task elements 1 and 2, information processing task element, equipment probabilities 1 and 2, human probabilities 1, 2, and 3 (Askren and Regulinski, 1971), and mission recycle probability.

Simulation Model Input Data - The model input data is categorized into system and block data. The system data applies to all blocks. The "GET LIST" option of PL/1 allows the input data to be free format. The only restriction is that each data item must be separated by one or more blanks. This process is an advantage over the FORTRAN card boundary approach. These system data are provided at a minimum:

- Network title
- Number of replications
- Number of blocks
- Equipment probability switch

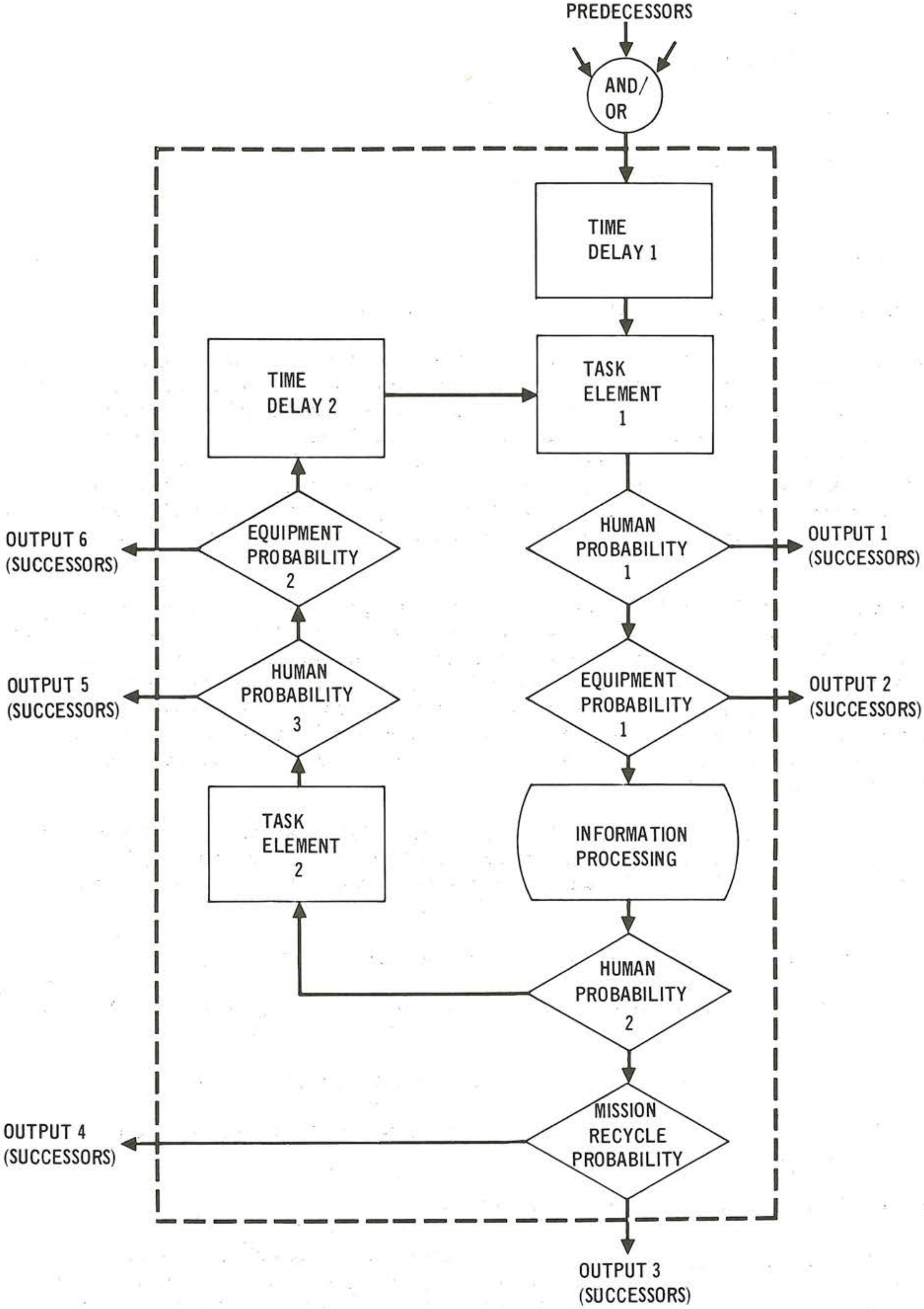

Figure 1. Block Structure

- Number of individuals
- Individual titles
- Type of distribution
- Calendar switch
- Number of equipment
- Equipment title
- Number of plots and plot selection switches.

Each block in the network contains these 12 data elements: Task block title and number; number of task block predecessors; and/or acceptance switch; individual assigned to block; task to be interrupted (optional); sensory mode data for task 1 and 2 elements; equipment probabilities; human probability factors; mission recycle probability; recycle limit; task 1, information processing, and task 2 elements mean and standard deviation; and equipment associated with task 1 and 2 elements. Temperature, stress, cohesiveness, altitude, and undefined (spare) environmental factors can be provided as input variables.

Our experience in coding data to describe large networks has shown that, in many cases, sets of similar blocks appear. Our major loop approach somewhat relieves the problem of coding similar blocks. However, there still remain cases where a similar block must be coded several times. The MDC model has the capability for the user to create a library of standard blocks. Therefore, when preparing input data for a simulation run, blocks are pulled from the library, modified to any extent desired, and used to augment the sets of blocks described in the card data deck.

In order to create and update the library, a file maintenance program has been coded in PL/1. This program is completely separate from the PL/1 simulation program. The maintenance program performs the following functions:

- Create new library, and produce printed library listing
- Delete specific blocks from existing library, and produce updated listing
- Add blocks to existing library, and produce updated listing
- Delete and add blocks to existing library in the same tune, and produce updated listing
- Produce listing of existing library.

Simulation Model Output Data - The detailed and summary output data are a check of input data, error message, optional calendar printout, network summary data per replication, network activity plots (up to 10), and statistical summaries such as mean, standard deviation, and measures of skewness and kurtosis. Timeline CALCOMP subroutines are incorporated. The mean start and stop times are available for each occurrence of task 1, information processing and task 2 elements for each task block in the network. This summarized information can be plotted on an off-line CALCOMP plotter. Plot selection switches used to control the contents of each plot are in figure 2. Figure 3 illustrates a typical plot. These data are provided in two-dimensional plots and have been utilized for detection of potential crew, student or instructor task overlaps. Potential task overlaps are detected from the plots for average task start and stop times up to 100 mission replications. These task overlap conditions have been analyzed for consideration in the following classification categories:

SELECTION NUMBER	CARD INPUT DATA	PLOT
1	0	ALL INDIVIDUALS
	1	INDIVIDUAL ONE
	2	INDIVIDUAL TWO
	3	INDIVIDUAL THREE
	4	INDIVIDUAL FOUR
	5	INDIVIDUAL FIVE
	.	.
	.	.
	.	.
	10	INDIVIDUAL TEN
2	A	ALL SENSORY MODES
	V	VISUAL SENSORY MODE
	R	RIGHT HAND SENSORY MODE
	L	LEFT HAND SENSORY MODE
	F	FEET SENSORY MODE
	C	COMMUNICATIONS SENSORY MODE
	I	INFORMATION PROCESSING SENSORY MODE
3	0	ALL EQUIPMENT
	1	EQUIPMENT 1
	2	EQUIPMENT 2
	.	.
	.	.
	.	.
	999	EQUIPMENT 999

Figure 2. Plot Selection Switches

- o Potential task overload
- o Sufficient time for shift of task
- o Left hand required for normal right hand operation
- o Processes more than one signal
- o Overlap due to computerized sampling average for mission replications.

Figure 3 also shows that the technique is useful for the establishment of performance measurement criteria. Sufficient output data are available for construction of individual task error ratio curve as a function of trials established by part task simulation. This type of plot is in figure 4.

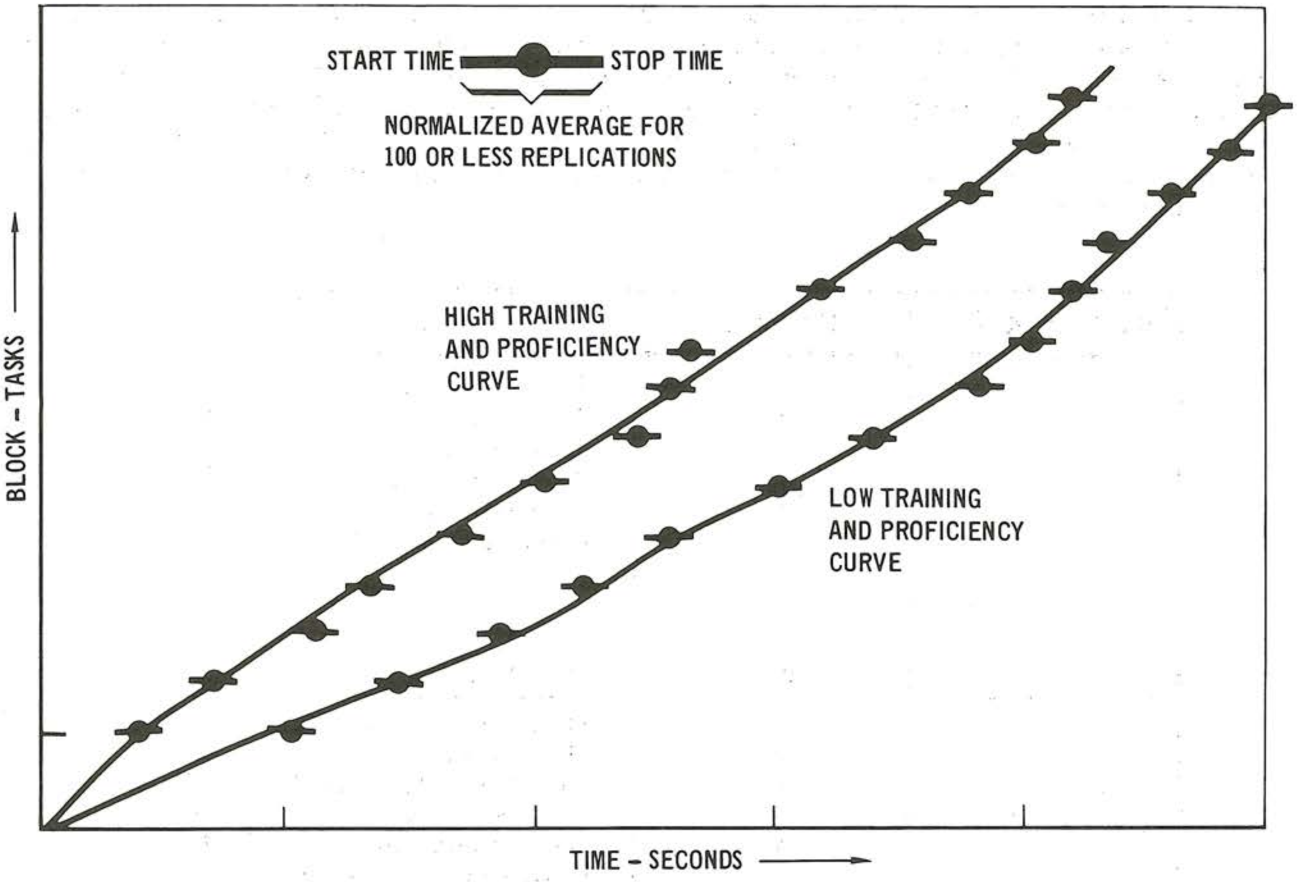

Figure 3. Typical Time-Line Calcomp Plot

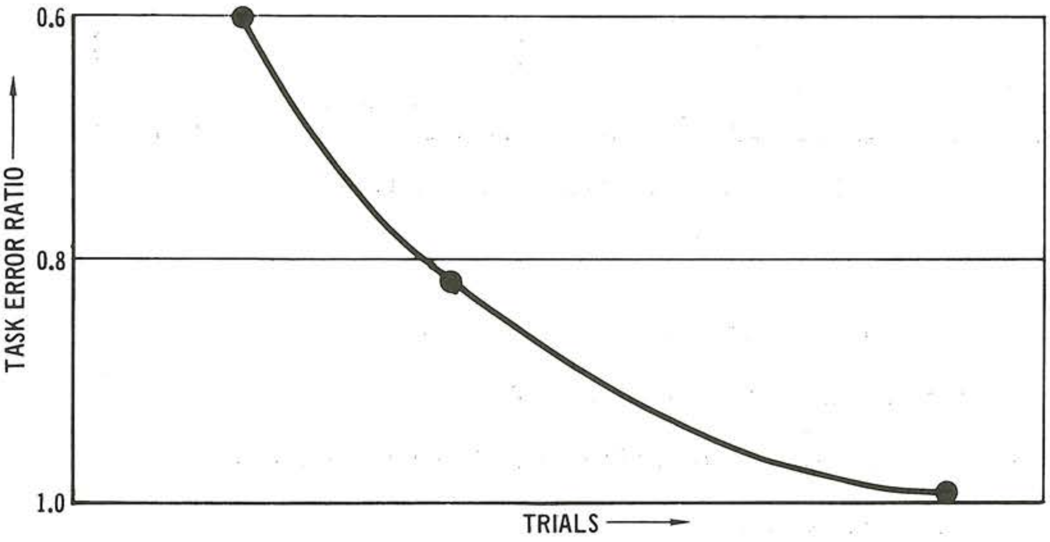

Figure 4. Typical Individual Task Error Ratio vs Trials

Plots illustrating the delays (queuing information) experienced by students due to instructor overload are also provided as a function of variable automatic versus manual diagnosis.

SUMMARY

Our model incorporates at least the following considerations in generating the quantitative criteria of mission, crew, student, or instructor performance:

- Each simulated individual workload as a function of time available and remaining tasks
- Impact of individual interaction and cohesiveness
- Independent proficiency of each individual
- Mission or session duration variable influencing task criticality
- Intercommunication constraints among individuals
- Effects of individual decisions.

The technique evaluates all performance data within the context of objectives or contingency events to derive an operational or training definition of minimum acceptable level of task performance, in terms of explicit criterion values. This validated model is useful for selection of display and control configuration from many alternatives, establishment of display and control requirements based on performance and utilization, and identification of efficient and practical group sizing for operational and training situations. It also establishes automated and manual operations affects on task loading and reliability, identifies performance measurement criteria, and establishes diverse add-on requirements impact on operational and training activities.

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MEASUREMENT OF AIR TRAFFIC CONTROLLER PERFORMANCE

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To supply technical support for the concept formulation of an Air Traffic Management System, a test vehicle was developed to evaluate certain automated enroute air traffic control concepts in a tactical environment. Designated the Semiautomatic Flight Operations Center (SAFOC), it was evaluated by its ability to control simulated Army air traffic, flying according to realistic tactical scenarios. The target simulators at the National Aviation Facility Experimental Center (NAFEC) provided the air traffic input, and automatic data collection techniques gathered the output.

One of the primary purposes of the evaluation was to test the ability of air traffic controllers to work with automated equipment while retaining the final decision on any control commands. It is felt that the data collection, reduction, and evaluation techniques to be described in this paper are of general interest in establishing and quantifying human performance measures in a semi-automated environment.

The technical objectives of the enroute test bed are:

1. To regulate Army air traffic under instrument flight rules

2. To provide flight following capability under visual flight rules

3. To improve information transfer among system elements and units being supported

4. To provide computer facilities to automatically analyze air traffic data for display and decision-making by an operator

5. To provide a means for making commanders aware of the current air traffic situation for overall tactical planning

6. To perform specific functions required for air traffic regulation

SYSTEM FUNCTIONS

SAFOC includes data processing, radar processing, display, and manual backup subsystems to provide the following capabilities:

1. Flight data processing
2. Flight following
3. Flight handoff
4. Identification assistance
5. Emergency assistance
6. Air/ground coordination
7. Ground/ground coordination

SAFOC provides the following methods of flight tracking: digital data link, radar beacon, radar skin return, and flight plan following.

SAFOC TEST CONFIGURATION

Figure 1 shows the test operations and information flow diagram. The scenario generator program generates scenarios and scripts based on realistic scenarios. The scripts are followed by pilots, who simulate actual flights, using target generators which are part of NAFEC's data link simulation.

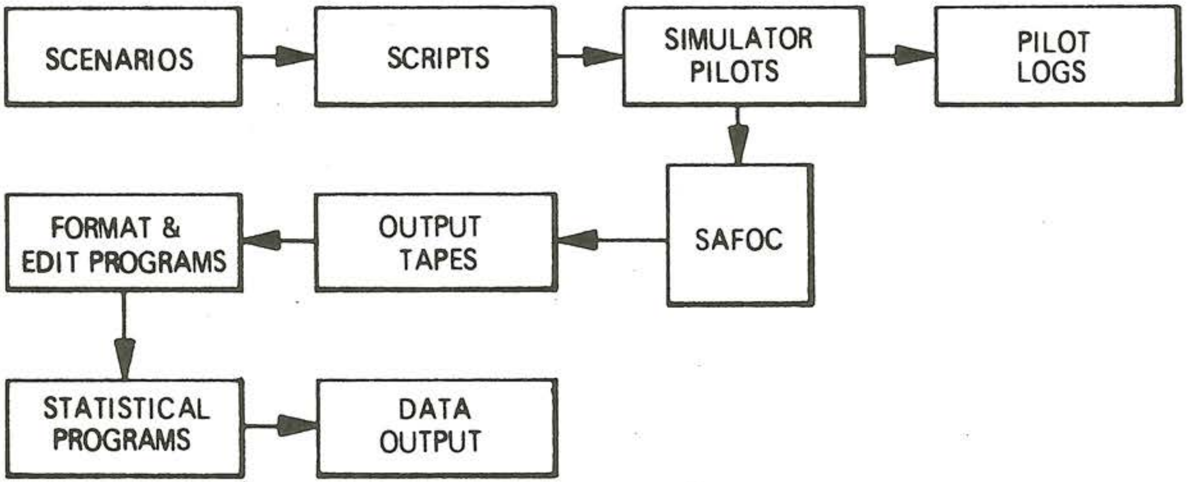

Figure 1. SAFOC Test Operations and Information Flow Diagram

Using a predetermined, operational-procedural mode, the system controls the simulated flights and produces exhaustive time histories on magnetic tape. These histories include all actions performed by the equipment or by the controller. The raw output data tape and the target generator history tape are processed using a series of formatting and editing programs, after which statistical programs generate the desired data output.

Evaluation of the SAFOC consists of a series of tests including Preliminary testing for familiarization with the equipment and training of controllers; Phase I testing to determine the best operational method, to rank controller performance, and to find the system performance measures and effectiveness measures; and Phase II testing to evaluate system and controller performance, using realistic tactical scenarios, and to recommend changes to optimize the SAFOC.

PHASE I TEST PLAN*

To evaluate controller performance and to determine the best method for operating the SAFOC, a series of tests was planned and conducted using the NAFEC simulation facility. The tests consist of a series of scenarios of three different traffic levels. Each of four controller teams operate the SAFOC according to four different operational-procedural combinations. The outputs, consisting of system effectiveness measures, are ranked to determine the best operational-procedural mode. Figure 2 shows this experimental design.

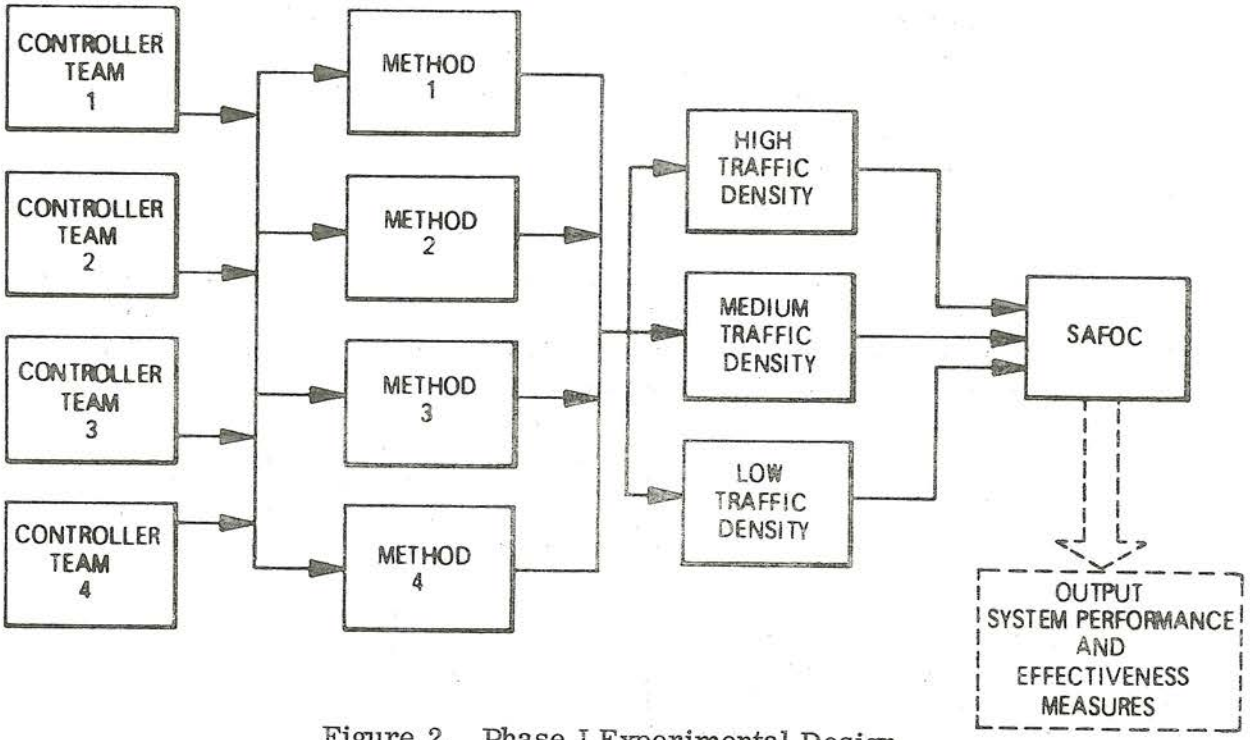

Figure 2. Phase I Experimental Design

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* "Phase I Test Plan for a Semiautomatic Flight Operations Center (Design of Experiments Program)", July 1, 1970, Contract No. DAAB07-69-C-0040.

SYSTEM PERFORMANCE MEASURES. Evaluate the individual items which, in total, influence the system effectiveness. The performance measures represent, for example, the actual contributors to total workload, and it is through improvements in the performance measures that the effectiveness measures can be improved.

1. Time to perform each service
2. Service rate
3. Waiting time for service
4. Event time history
5. False dismissal probability
6. Actual density history
7. Queue lengths
8. Typewriter errors
9. Near miss history
10. Communication time history
11. Number of impossible requests
12. Altitude change history
13. Closest approach history

SYSTEM EFFECTIVENESS MEASURES. (SEMs) are used to provide relative rankings of the operational-procedural modes and to evaluate relative controller team performance. The following measures are chosen because they represent the characteristics most important to the user:

Safety is the number of near misses per aircraft mile flown.

Controller workload is the total time for all flight servicing.

Communications workload is the total time spent in communications.

Delays are the actual departure time delay from the planned departure time. Delays are important in a tactical situation.

Throughput is defined as the actual number of flights entered during steady state divided by the number of entries planned in that time.

Capacity is the peak flight density safely handled by the system.

Uncontrolled time is the total time of flights within the control area without being controlled by the system.

MATHEMATICAL MODEL AND CONTROLLER TEAM PERFORMANCE

It is possible to rank the controllers on some measurable characteristics. For this ranking the C teams in R replications using different but equivalent scenarios are used. In essence, random trials of the controllers' ability to handle repeated scenarios are performed to determine whether the controllers are significantly different in their abilities. If they are different, they are ranked in order of their abilities to determine those needing additional training.

Table 1 shows the symbology of the effects (effectiveness measures) resulting from replications of different scenarios, by each controller, and indicates the sums to be performed. Table 2 shows the usual analysis of variance for a two-way classification based on a mixed-model of fixed teams and random samples from the hypothetical population of replication observations.

When the scenarios are run, the data (such as the workload times of each controller) consisting of the X_{ij}'s shown in table 1 is operated on by performing the column and row sums, followed by the operations shown in table 2. Then the sums of squares and mean squares shown in table 2 are computed. The F ratio is computed:

$$(1)\quad F = \frac{S_2\,(R - 1)}{S_3}$$

TABLE 1. EFFECTS OF REPLICATIONS

TEAMS						
Replications	1	2	·	·	C	Row Sum
1	X_{11}	X_{12}	·	·	X_{1C}	$\sum_{j}^{C} X_{ij} = C\overline{X}_{1.}$
2	X_{21}	X_{22}	·	·	X_{2C}	$\sum_{j}^{C} X_{2j} = C\overline{X}_{2.}$
·	·	·	·	·	·	
·	·	·	·	·	·	
R	X_{R1}	X_{R2}	·	·	X_{RC}	$\sum_{j}^{C} X_{Rj} = C\overline{X}_{R.}$
Column Sum	$R\overline{X}_{.1} = \sum_{i}^{R} X_{i1}$	$\sum_{i}^{R} X_{i2} = R\overline{X}_{.2}$			$R\overline{X}_{.C} = \sum_{i}^{R} X_{iC}$	$\sum_{i}^{R} \sum_{j}^{C} X_{ij} = RC\overline{X}_{..}$
C = Number of teams R = Number of replications						

TABLE 2. ANALYSIS OF VARIANCE FOR A TWO-WAY CLASSIFICATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE
Replications	$S_1 = \sum_{i}^{R} (\overline{X}_{i.} - \overline{X}_{..})^2$	R-1	$S_1/(R-1)$
Teams	$S_2 = \sum_{j}^{C} (\overline{X}_{.j} - \overline{X}_{..})^2$	C-1	$S_2/(C-1)$
Error	$S_3 = \sum_{i}^{R} \sum_{j}^{C} (X_{ij} - \overline{X}_{i.} - \overline{X}_{.j} + \overline{X}_{..})^2$	(R-1) (C-1)	$S_3/(R-1)\ (C-1)$
TOTALS	$S_4 = \sum_{i}^{R} \sum_{j}^{C} (X_{ij} - \overline{X}_{..})^2$	RC-1	---

where S_2, S_3 and R are defined in table 2. Reject the null hypothesis of no team difference if (1) exceeds the α point of the F distribution with (C-1) and (R-1) (C-1) degrees of freedom. For example, if α equals 0.05, C equals four and R equals two, then the critical value is:

(2) $F_{0,\ 0.05,\ 3,\ 3} = 9.28$

If the computed value of F was larger than 9.28 one could say that the controllers performed their tasks with significantly different capabilities and that similar tests would repeat this conclusion with a 5 percent risk of being in error.

If we wish to rank each of the teams with respect to every other team, Tukey's multiple comparison procedure can be used. This consists of taking the difference between every pair of team performance means computed during the test:

(3) $B_1 - B_2 = Z_1$

$B_1 - B_3 = Z_2$

$B_1 - B_4 = Z_3$

$B_2 - B_3 = Z_4$

$B_3 - B_4 = Z_6$

where B_ℓ is the mean workload performance parameter of ℓth team

$$B_\ell = \frac{1}{R} \sum_{i}^{R} X_{i\ell}$$

We then compute:

(4) $Z_1 - \frac{S}{\sqrt{2}} q_\alpha \le \delta \le Z_1 + \frac{S}{\sqrt{2}} q_\alpha$

where $S = \sqrt{S_3/\ (C-1)\ (R-1)}$

q_α = critical value for the Studentized Range.

The value of q_α is extracted from the indicated table at some value of α (say 0.05) and for the error degrees of freedom (3 in the example). If (4) contains zero (that is, if the left hand term is negative and the right hand term is positive) then the difference Z_1 is not significant. This is performed for the remaining Z's and rankings are achieved on the basis of the relative values of (4). For example,

$$(5)\quad \begin{array}{cccc} B_2 & B_1 & B_4 & B_3 \\ \cline{1-2} \\ \cline{2-3} \\ \cline{3-4} \end{array}$$

where the underlines might indicate no significance between differences in B_2 and B_1 but significant differences in B_2 and B_4. We would then conclude that Team 2 is not significantly better than Team 1 (at the 5 percent level of significance) but that the difference in performance betweem Team 2 and Team 4 is significant. This result could be used to indicate that Teams 3 and 4 needed additional training to bring them up to Team 2 and Team 1.

SAFOC DATA COLLECTION

A write-only magnetic tape unit records data directly from the SAFOC computer memory using an I/O channel. The data directly accessible to the tape unit is raw data, not necessarily the data to be processed by analysis or statistical programs. To demonstrate the difference between the two types of data, the following is a partial list of data variables of interest in statistical processing:

- Number of conflicts versus flight density
- Departure queues
- Handoff queues
- Alert queues
- Number of impossible requests
- Departure rate
- Arrival rate
- Alert rates
- Service request rates
- Waiting times in queues

- Communication channel occupancy
- Total fly-through time
- Simulation fly-through time
- Mean service times

None of the above are directly available from the computer memory. The form of most data in computer memory involves the data related to flight plans; the activities at the console and typewriter, such as illuminated or blinking pushbuttons; and the SAFOC status, such as the display modes and content.

The method of obtaining data from the SAFOC is to record events on magnetic tape as they occur. For example, consider the measure of alert waiting time. This is measured by the time between the setting and the resetting of an alert blink bit. When an alert blink bit is set, the type, the time, and the flight number, for which it is being set, are recorded on magnetic tape. When the blinking alert is answered by a controller, the alert blink bit is reset and this event is again recorded on magnetic tape. In order to obtain the alert waiting time, the data reduction program must extract these events from the magnetic tape and compute the difference in time between set and reset of the blink bit for that particular flight.

Alert service queues are also obtained in the data reduction program by extracting the times of set and reset of an alert blink bit. Whenever a blink bit is set, a counter is incremented by one. Whenever a blink bit is reset, the counter is decremented by one. The time history of this counter is a measure of alert service queue length throughout the run.

The Magnetic Tape Synchronizer (MTS) is used to collect SAFOC data by interfacing with one to four Magnetic Tape Units (MTU) and with one of the I/O channels of the SAFOC General Purpose Computer. The MTS provides control of four MTU's through programmed instructions received from the SAFOC computer. The MTS controls data transfers between the computer and the MTU's in both directions; it controls tape positioning, and it supplies status to the computer on itself and any MTU. MTS operations are initiated by programmed instructions received from the computer. Once an operation has been initiated, communication between the computer and the MTS is accomplished by input data requests, output data requests, interrupt requests, and acknowledge signals. This allows transfer of data into and out of memory without impeding program operation.

In order to obtain the SAFOC data, "bugs" are inserted into the operational SAFOC program at the appropriate locations causing data to be recorded on magnetic tape related to particular events; such as:

1. Event occurring (handoff blink, conflict alert, flight hook, etc.)
2. Time event occurred

3. Console initiating event

4. Flight number associated with event (more than one flight number for conflicts).

DATA EXTRACTION

When both the SAFOC history and target generator history tapes are ready for processing, tape data is edited and converted so that the information which will be used for statistical processing is directly available. The handling of this data is performed by the Format and Edit programs. These programs convert the data and store it in appropriate lists. From these lists magnetic tape files are prepared. For the purpose of eliminating data, which may prevent proper statistical processing, a printout of these data lists is also produced. After examining the printout and determining which is "bad data", the Format and Edit programs are rerun, the "bad data" removed, and new magnetic tape files generated.

These files provide the input data for the Analysis and Statistical Programs, which use "packaged" subroutines such as those provided in the Biomed Statistical Package. The elements of such a package are used as subroutines which are "called" as required for the specific statistical processing to be performed. Outputs are histograms and other statistical data such as means, standard deviations, etc.

PHASE I TEST RESULTS

Because a lesser number of controllers were available, the planned testing of four teams was changed to test individual controllers. The results of the controller performance analysis indicate no significant differences in the system effectiveness measures with the results of all operational methods combined. That is, an F test shows that the variation among controllers is not significantly larger than the variation among the test results for the same controller.

A comparison of the incomplete events for each controller was performed. An incomplete event is an alert not answered or a service not completed. An F test indicates that there were no significant differences in the number of incomplete events among the controllers at the 0.1 level of significance.

In addition to the effectiveness comparisons, tests were made to determine if the differences in controller errors per run were significant. The average numbers of controller errors per Phase I test were found to be significant, and the following ranking of the controllers (designated as C, D, L, M, Sk, St, W) was performed on this basis:

Phase I Tests

Ranking: $\underline{\text{L M}}\ \underline{\text{W St C}}\ \underline{\text{Sk}}$

Since controller errors exhibited significant differences among controllers, regression analyses on controller errors versus controller experience, education, and aptitude scores were tried. These analyses did not indicate any significant relationships between controller errors and the other factors.

PHASE II TEST RESULTS

In Phase II, the man/machine system was evaluated using both special purpose scenarios and realistic tactical scenarios supplied by the Army.

Statistical tests indicate that there were no significant differences in controller performance observed in the effectiveness measures used for the tests. Significant differences were observed in the average number of controller errors per run, however, resulting in the following rankings of the controllers:

Phase II Special Purpose Scenarios

Ranking: $\underline{\text{L}}\ \underline{\text{C D Sk St}}\ \underline{\text{W M}}$

Phase II Realistic Scenarios

Ranking: $\underline{\text{L D W C}}\ \underline{\text{M}}\ \text{Sk St}$

(not ranked)

EXPERIENCE EFFECTS

C and M were the most experienced controllers while L, W and D were the least experienced. The results indicate that previous air traffic control and radar experience does not necessarily guarantee the best performance. D entered the program more than a year later than all other controllers, and had less time on the system; yet his performance was near the top in terms of controller errors. Thus, it cannot be said in this case that either experience on the system or related air traffic control experience has a great bearing on controller performance.

APTITUDE EFFECTS

Differential Aptitude Tests (DAT) were conducted in the training program. Regression analyses were performed on controller errors versus experience, education and DAT scores. The only significant fit was found for average DAT score and the realistic scenario controller errors. The results indicate that higher aptitude test scores were correlated with better performance.

LEARNING EFFECTS

The tests were run in the following order:

Phase I tests
Phase II tests (special purpose scenarios)
Phase II tests (realistic scenarios)

The data does not indicate any improvement with time attributable to learning. In fact, the data indicates performance degradation with time. The degradation in performance is probably a result of the differences in the scenarios and motivation effects, rather than any negative learning effect.

MOTIVATION EFFECTS

Though motivation effects could not be quantified, it was the opinion of the test conductor that motivation was the primary factor effecting controller performance.

During the tests, an independent subjective evaluation of controller motivation was made by the test conductor:

Phase I Subjective Analysis of Motivation

Ranking: L St M W C Sk

Phase II (Special Purpose Scenarios)

Ranking: L Sk St D C W M

Phase II (Realistic Scenarios)

Ranking: L D C W M

These ranks were compared with the rankings by average number of errors per run and the Hotelling and Pabst's Spearman Rank-Order Correlation Test* applied. Ties were broken based upon the nature of the errors. Controllers with least serious errors were given better ranks.

The rank correlation test is as follows:

Compute Spearman's rank difference correlation coefficient

$$r_s = 1 - \frac{6D}{n(n^2 - 1)}$$

$$\text{where } D = \sum_{i=1}^{n} d_i^2$$

d_i = difference between the rankings for controller i

n = number of controllers

The null hypothesis to be tested is H_0: Ranks are independent versus the alternate hypotheses of positive correlation.

If $D \leq D_{\alpha}$ where D_{α} is obtained from tables of the critical lower-tail values of D for Hotelling and Pabst's Spearman Rank-Order Correlation Test for a level of significance α then reject the hypothesis of independence.

The results of this test were:

Phase I: $r_S = 0.886$, $D = 4$, reject H_0 at $\alpha = 0.025$
Phase II: $r_S = 0.75$, $D = 14$, reject H_0 at $\alpha \cong 0.035$
Realistic: $r_S = 1.0$, $D = 0$, reject H_0 at $\alpha = 0.01$

These results indicate that there is no reason to reject the hypotheses of positive correlation between motivation and average errors per run for any of the test situations.

CONCLUSIONS

The results of this evaluation indicate a significant consideration which must be made in the design and testing of any semi-automated system, where a human operator is expected to interface closely with data processing and display equipment.

To attain the level of operator performance necessary to accurately measure system performance, operator motivation must be maintained. In this evaluation, a high frequency of controller errors was attributed to deteriorating motivation, based on the judgment of the test conductor. As the frequency of controller errors rose, the evaluation of system effectiveness was impaired.

Alternatively, the system can be designed in such a way as to reduce the dependency of system effectiveness on the variability of operator performance.

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* Bradley, James V., Distribution-Free Statistical Tests, 1968, Prentice-Hall Inc., Englewood Cliffs, N. J., pp. 91-96.

USE OF DIGITAL COMPUTERS
FOR REAL-TIME SIMULATION OF TACTICAL RADAR

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Tactical radar training devices have historically been restricted to the use of multiple servomechanisms to mechanize the radar antenna scan and stabilization equations for use in target and landmass simulation. It is now possible (and, in fact, preferrable) to perform the complete antenna simulation using a small general purpose digital computer and a small amount of special digital hardware. A recent training device has demonstrated the outstanding advantages of this approach. Before discussing this new technique, we should establish the system requirements and discuss some of the previous simulation techniques.

Typical radar training devices are operated as a sub-system within an aircraft training device. The radar simulator will receive information defining the aircraft position (latitude and longitude), the aircraft attitude (pitch, roll, heading, etc.), the gyro attitude, and the radar mode of operation. The radar simulator must then provide accurate positioning of the landmass data (a photographic filmplate), simulate the motion of the antenna,as performed in the actual aircraft system, and provide accurate real-time antenna position information to the target generator (in aircraft reference), the landmass video generation subsystem (in earth reference), and the radar indicator (in gyro reference).

In most tactical radar systems, the antenna is gyro stabilized so that the gyro platform remains horizontal in normal operation. However, it is usually necessary to simulate conditions in which the platform is not horizontal. This means that the antenna position must be known in three separate coordinate systems; aircraft, gyro platform, and earth coordinates. The target generator usually needs antenna position in aircraft coordinates, the antenna positioning signals are usually generated in the gyro platform coordinates, and the landmass information (filmplate) is in the earth coordinates. Thus,it is necessary to perform two coordinate transformations, since the position in gyro platform coordinates is known to follow the prescribed scan pattern.

In general, radar simulators generate and present the radar video at (or near) the actual PRF used in the aircraft. This is especially critical to target/ jammer simulation and electronic counter-measures. The PRF rate of typical tactical radars range from 200/sec. to 2000/sec. This means that a new value of antenna position is needed for every PRF and the system must have adequate precision and resolution to destinguish the angular difference of each successive sweep. This is indeed a tough requirement. At the highest PRF (2000/sec.) there is only 500 microsec. between radar pulses to perform computations in the computer.

A brief description of the previous antenna simulation techniques is helpful in understanding the relative advantages and disadvantages of the newer techniques. Servomechanisms offer a physical model approach using servos resolvers, synchros, modulators, demodulators, d. c. restorers, digital shaft encoders, etc. A typical radar simulator using these devices is shown in figure 1. This type of system contains a lot of mechanical moving parts which require precise alignment and much maintenance (motors, tachometers, resolvers, synchros, encoders) and are not overly reliable. The electrical problems are noise generation, complex wiring, and difficulty of changing configuration or parameters for different modes of operation. The modulators demodulators, and d. c. restorers add some error and require careful adjustment. The overall complexity of this system makes it generally difficult to adjust and maintain.

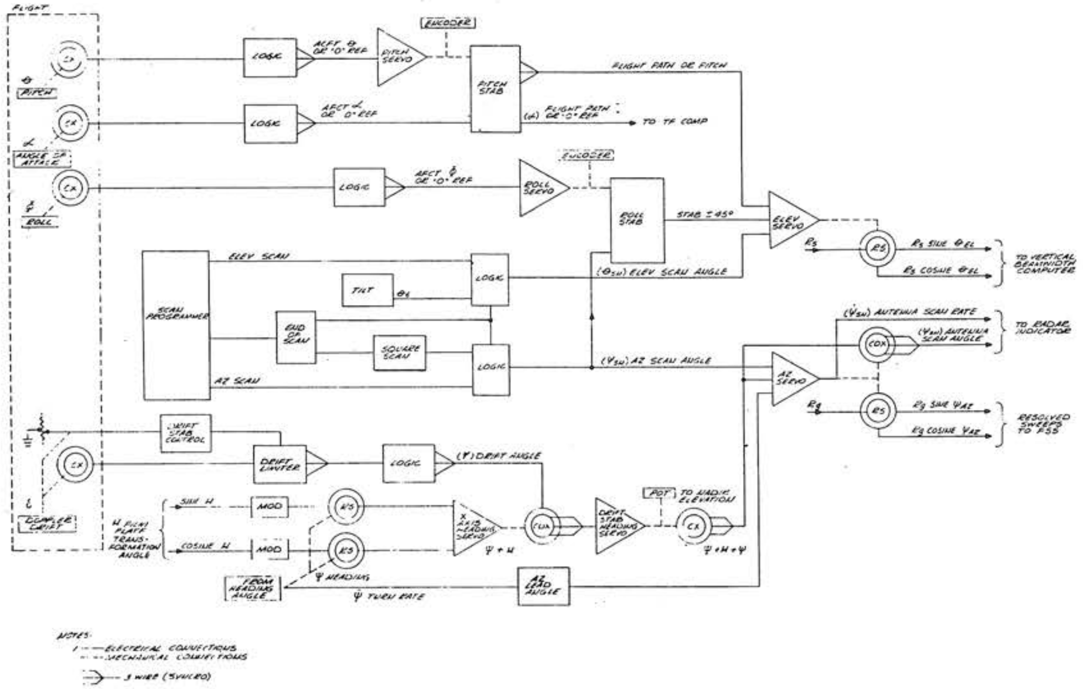

Figure 1. A Typical Simulation using Servomechanisms

Utilizing a general purpose mini-computer, a much better radar simulator can be built improving on every aspect both technically and economically. The basic system design is shown in figure 2,and the computer configuration is shown in figure 3. The most important techniques are the multilevel priority interrupt system, the Sine/Cosine function generator, the MDAC (Multiplying Digital to Analog Converter), and the software interpolation techniques.

The basic approach to the problem is based on the multilevel priority interrupt system as illustrated in figure 4. The highest priority is used for PRF rate computations (up to 2000/sec.), the next level is used to compute the coordinate transformations and all other computations not requiring PRF

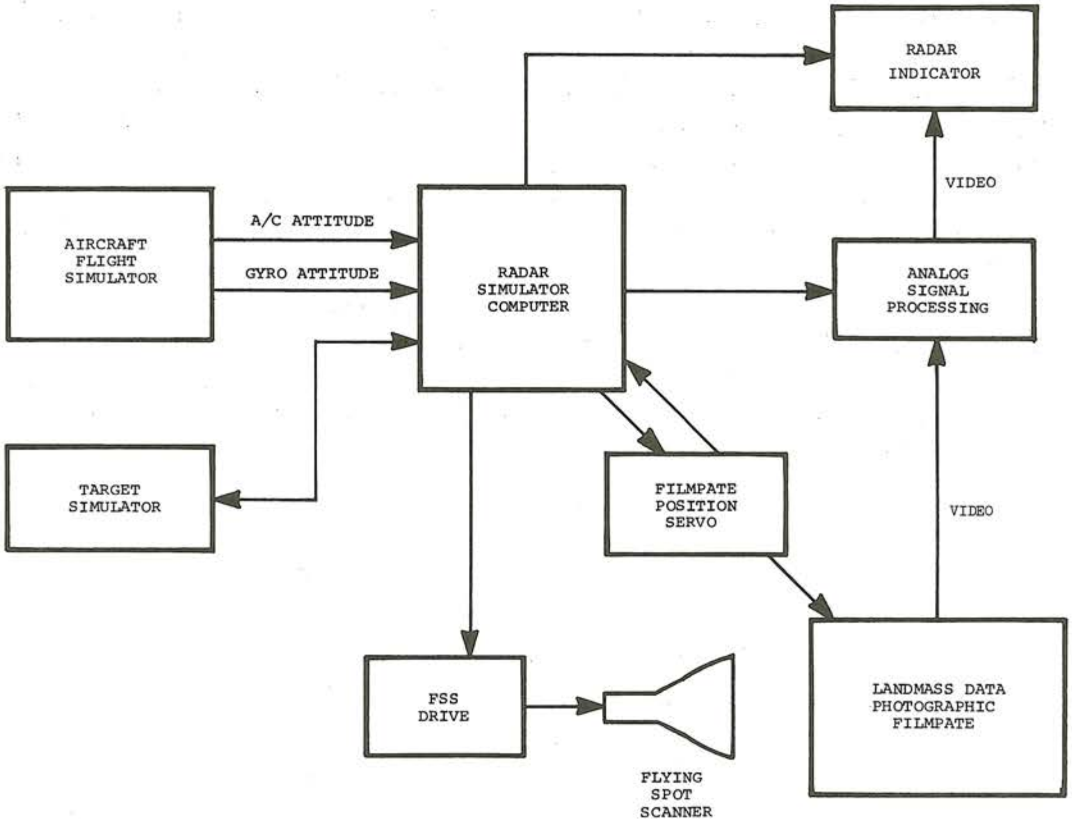

Figure 2. Simplified Block Diagram

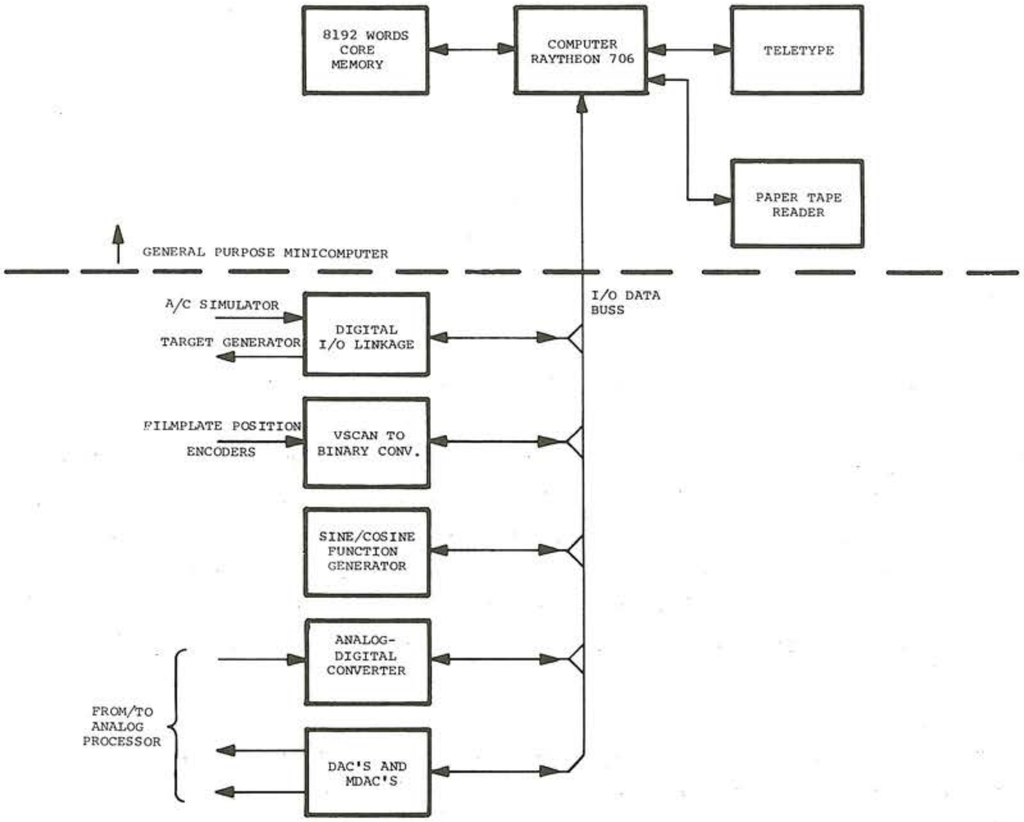

Figure 3. Computer Configuration

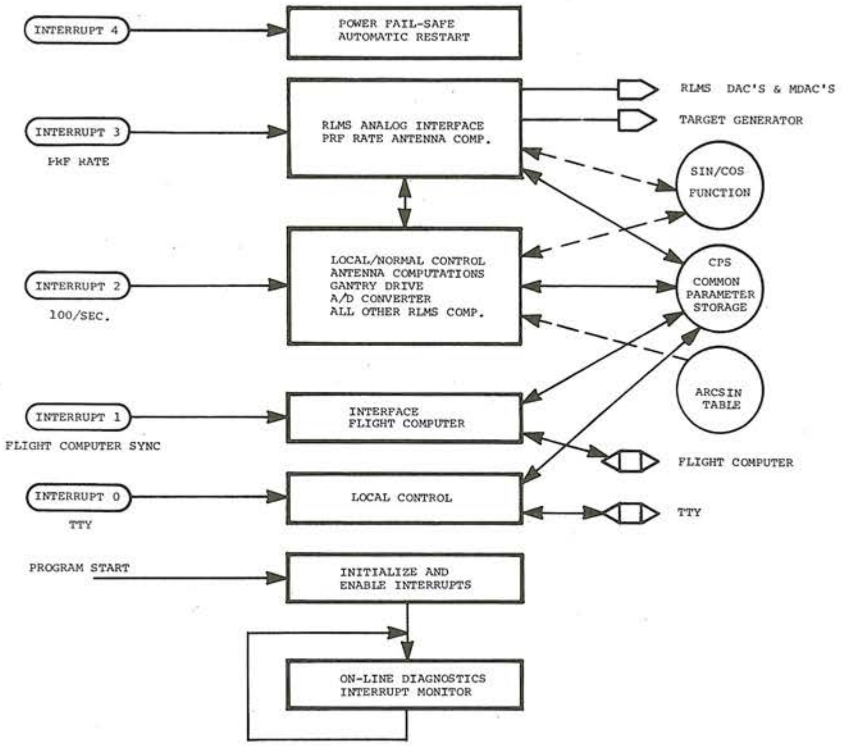

Figure 4. Software Architecture

rate update at a fixed rate of 100/sec. A lower level is used for interface between the radar simulator and the aircraft simulator at a rate of 20 times per second to transfer aircraft and gyro attitude. The lowest level is used for interface with the teletype to allow real-time operator interaction with the simulator. The "mainloop" is used for diagnostics and other nonreal-time tasks. This use of the priority interrupts reduces the computer overhead and provides an efficient and convenient way of partitioning the computer time.

At the maximum pulse rate of 2000/sec., it is not possible to perform all the necessary calculation. Thus, the highest rate interrupt (2000/sec.) is used primarily for interpolation of the values computed at the 100/sec. rate and for resolving the angles into X and Y components for the radar scanner and the radar indicator. A simple linear interpolation is adequate to follow the antenna motion. The very complex coordinate transformation equations are solved at 100/sec. rate.

Sine and Cosine functions are used many times for solving the coordinate transformations and for resolving angle into X, Y components. A software subroutine to calculate these functions would require far too much time. Therefore, a special hardware Sine/Cosine function generator is used to give very fast computation of Sine and Cosine. Figure 5 shows a simple block diagram of the Sine/Cosine function generator. An interpolation scheme is used to determine the values of Sine from 0 to 90 degrees. The Read-Only-Memory provides 256 full words (16 bits) and 256 half words (8 bits). The address selects one full word and one half word which, when added together, will give the value for that angle. The quadrants and the Cosine function are then obtained from the Read-Only-Memory by complementing either the address or the answer or both. This technique provides a resolution of .02 degrees with an accuracy of ±.02%. The total computer time required for any Sine or Cosine is only 2 microseconds (a single instruction).

The MDAC (Multiplying Digital to Analog Converter) provides the means for the digital computer to control the amplitude of various analog amplifier waveforms. The MDAC difers from a normal digital to analog converter only in that the reference voltage need not be constant. The digital value from the computer is in effect, multiplied by the analog voltage. This is primarily used for driving the radar scanner and the indicator. Analog signals as high as 100 KHZ can be controlled by the MDAC with an accuracy of .05%.

Using these techniques, this system has clearly shown that the use of a digital computer offers many advantages. The system is very versatile. It can more easily be modified to respond to various modes of operation or to simulate changes in the radar system. The computer can be used to perform many other tasks such as diagnostics, and automatic checkout or monitoring of parameters (power supplies, line voltages, temperature, etc.). The computer almost completely eliminates moving parts, thereby, greatly increasing reliability and decreasing maintenance. The computer provides much greater accuracy and resolution and greatly reduces the amount of adjustments required to calibrate the system. The list of advantages is limited only by the imagination. Further modifications can be easily accomodated by the remaining 30% of the computer time and core memory.

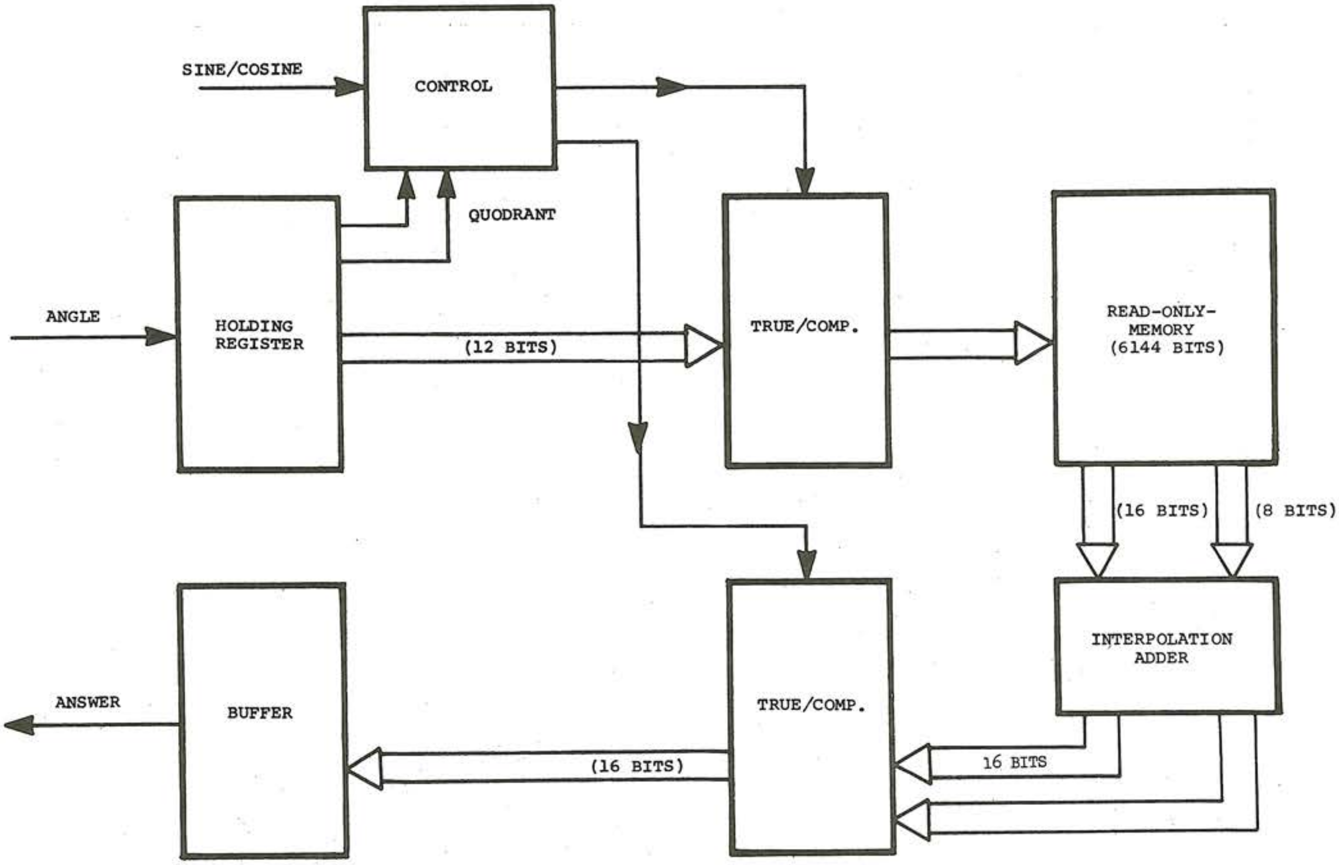

Figure 5. Sine/Cosine Function Generator Block Diagram

DIGITAL RADAR LANDMASS SIMULATION

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What is landmass radar? Landmass radar may be defined as any radar which scans the ground for the purpose of navigation and or target identification. Landmass radar may be either airborne or shipboard (surface).

The airborne landmass radar, which is used only for navigation purposes, provides the aircraft navigator with information about the terrain and reflectivity of the scanned area of a more or less gross nature. For example, the outlines of cities, hydrographic features, ridge lines and shadows caused by intervening peaks are observed, and by comparison to the maps and charts, the flight of the aircraft is navigated.

A much more precise-type radar is that which is used for either terrain avoidance navigation and/or target identification. When on a terrain avoidance-type mission, flight close to the deck, the aircraft navigator is very much concerned with the exact location of the underlying hills and valleys, as well as the accurate determination of their elevation. The use of the aircraft's landmass radar for the purpose of target identification requires a high degree of resolution for the equipment and considerable operator skill since this mode of operation would normally require the acquisition of a small target (e.g., a building) at considerable distance.

The shipboard (surface) landmass radar is simpler than the airborne landmass radar in that there is one less degree of freedom; it is located at a fixed altitude. Like the airborne systems, the surface landmass radars are used for navigation and/or target identification. These radars generally scan the shoreline at both great distance and within a harbor. Navigation within a harbor usually means radar determination of distance down to meters. This type radar is also used to guide fire control on the shoreline targets.

Radar Landmass Simulation: Radar landmass simulation is the simulation of the radar, which scans the ground, for the purpose of navigation and/or target identification. The device, which performs this function, is called a radar landmass simulator RLMS. Such devices are used to train navigators, navbomb operators, and bombardiers. These RLMS devices are also used for premission briefings of operational flight crews.

To date all such training devices have been of an analog type. The most successful, and that which is currently used, is the transparency radar landmass simulator.

In a transparency-type RLMS, the simulated radar display data is stored on a photographic transparency, which is read by a flying spot scanner. Two basic types of information are stored on these transparencies. They are terrain height and reflectance. Both types of data are coded as shades of "grey." This photo-optic information is then converted by a photomultiplier tube into an electrical signal.

The signals generated by the photomultiplier tubes are processed by analog computation hardware. This computation uses the terrain height and reflectance data from the transparency, as well as aircraft flight and radar display parameters to solve the radar equation. The resultant information is then sent to the simulated radar display scope.

There are two major variations on this transparency approach to the RLMS problem. They are: (1) A "factor transparency" system where there are two photographic plates, one for terrain height and one for reflectance; and (2) a color system where each type of information is stored as a separate color. The latter system must provide the additional optics to separate the colors.

For both types of transparency systems there exists a set of common problems. These are: (1) High initial cost of the photographic plates; (2) high cost of duplicate plates for additional trainer; (3) the inability to update existing plates (requires a re-manufacture of plates); (4) the opto-mechanical complexities of positioning and scanning the transparencies; (5) the need for a separate transparency and scanning system for each cockpit where multiple station trainers are required; (6) with the approximate 5,000,000:1 scale, missions requiring high resolution (such as terrain avoidance) are not possible. To solve these problems and to provide better training, digital radar landmass simulators, DRLMS, are being proposed.

<u>Possible Digital Radar Landmass Simulation</u>: There are several possible different types of digital radar landmass simulators, DRLMS. The major differentiating factor is the form in which the radar data is represented.

A straightforward method is to divide the map into squares, and for each square store a height value and reflectance. The resolution of this type of digital system is defined by the size of these squares. This is somewhat equivalent to the resolution of the data on the transparencies.

The resolution of the transparencies is approximately 250 feet. For an equivalent resolution using the straightforward method above, an area of 1500 x 1500 miles would require 10^9 words of data. A word consists of the necessary number of bits to represent the height and reflectance of each square.

The data required for a single ppi scan (135 degree sector 200 mile range) using the 250 foot resolution is approximately 2×10^6 words.

It can be seen from the above that the digital systems are faced with several major problems with respect to the radar data. These are: (1) Obtaining the required data in digital form; (2) storing this extremely large amount of data for real-time use; and (3) transferring this digital data from the mass storage devices to the processor in the available time.

In general, the solution to the data storage and transfer problem is found by trading an increase in data processing for a decrease in the amount of data, i.e., the use of some data compression scheme. In the larger sense this tradeoff is much more complex, involving many factors such as the training requirement, the resolution, inclusion or omission of effects, the amount and sophistication of the hardware, as well as price.

Of the various data compression schemes, two in particular are mentioned here. The first is a compression scheme where the area of interest is sectioned by a grid, (a coordinate system). This grid has a larger spacing than the fundamental resolution element. Associated with grid points are coefficients, which are then used, to reconstruct the terrain height at any particular resolution element by the use of a polynomial approximation. These polynomic approximation techniques are usually applied to the terrain height information since it is assumed that the terrain height function is well behaved.

The second major data compression scheme uses a planar surface fit, approximation of the three-dimensional surface by a set of flat plane surfaces. This, then, says the radar data can be defined graphically as a set of vertices and edges. The accuracy of the fit would determine the number of edges required.

The digital approach to the radar landmass simulation problem provides the capability of updating the data base by nothing more difficult than a program reading the update punch cards. It allows for multi-training station access to a single data storage. It eliminates optomechanical complexities since there are no servos or optical scanners, and allows for inexpensive duplication of the simulation data base. The predominant disadvantages of the analog radar landmass simulators are overcome by the DRLMS.

The Feasibility of DRLMS: In the past two or three years there has been much interest in digital radar landmass simulation. This interest has been found in both industry and DoD.

There has been much effort, particularly in industry, to demonstrate that the digital approach to radar landmass simulation is feasible, practical, and the correct direction in which to steer the wheels of progress. An analysis of each of these feasibility demonstrations reveals the rather common tact of looking at one particular portion of the entire DRLMS problem. Each of these demonstrations has generated a radar display of sorts, for obvious sales purposes, without the overall analysis of the total-system problem. The actual system requirements, based on the type of training required, have not been specified.

It might be well to consider a different approach to the simulation of each of the various types of landmass radar mentioned above.

Much of the industrial interest in DRLMS has been generated by the Air Force procurement of an Undergraduate Navigation Training System, UNTS. This was an immense undertaking in that the system was initially specified as an all digital trainer with 46 trainee stations, each with free flight capabilities. The data base was to be at least half of the United States, at a resolution of 250 feet, expandable to 150 feet. There was much controversy along with protests, over this procurement, with bids ranging from 16 to 42 million dollars. The successful bidder was Honeywell Marine Systems Division, West Covina, California, with initial delivery scheduled for August 1973.

A concurrent project along with UNTS is that of providing the digital data. This undertaking is being carried out by the U.S. Army Topographic Command, and the U.S. Air Force Aeronautical Chart and Information Center.

The results of all these feasibility studies have in general shown that Digital Radar Landmass Simulation is possible, but not trivial or simple. There are many unknowns, most of which are in the realm of providing a quantitative as well as qualitative performance specification for each of the various requirements.

NAVTRADEVCEN's Research in DRLMS: With the interest generated in industry by the Air Force UNTS, NAVTRADEVCEN's role in the RLMS field has changed from providing the initiative for DRLMS research to that of providing the Navy with a comprehensive performance specification for the Digital Radar Landmass Simulation of each type of landmass radar.

The preparation of such a performance specification involves works in three particular areas. These are: (1) Determination of the training requirements, the degree of required realism, and how the training requirements relate to the quantitative parameters of such simulators; (2) to develop objective as well as subjective evaluation techniques to determine what constitutes a "good" simulation; (3) to evaluate various simulation schemes in comparison to a baseline system developed in-house via non-real time simulation studies. An example of such a comparison is shown in figure 1. Figure 1a shows the simulated radar display of the Scranton-Wilkes Barre, Pa. area, using the NAVTRADEVCEN base-line system (no data compression). Figure 1b shows the same area; however, the terrain data was compressed and decompressed using LaGrange Polynomials. The effects of the data compression are shown as a decrease in detail and a general smoothing of the terrain. But the major navigation features are still observed. The question remains, what is required for adequate training?

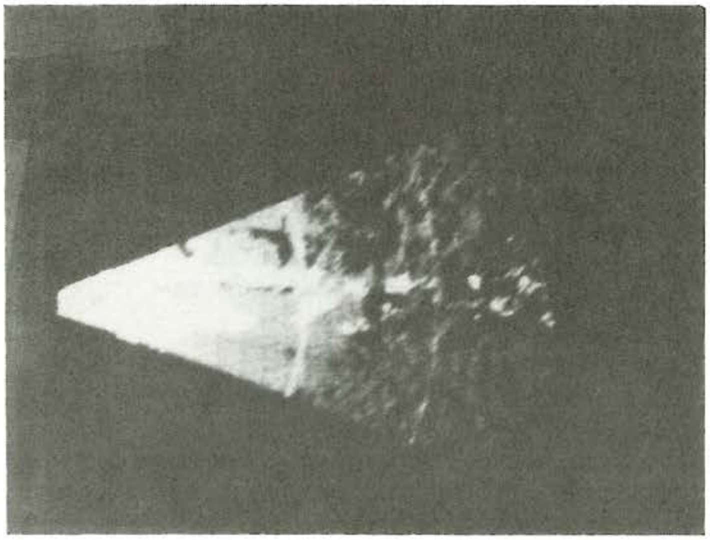

Figure 1a. Scranton-Wilkes Barre, Pa.
NTDC Base-Line System
(No Data Compression-7,000 Feet)

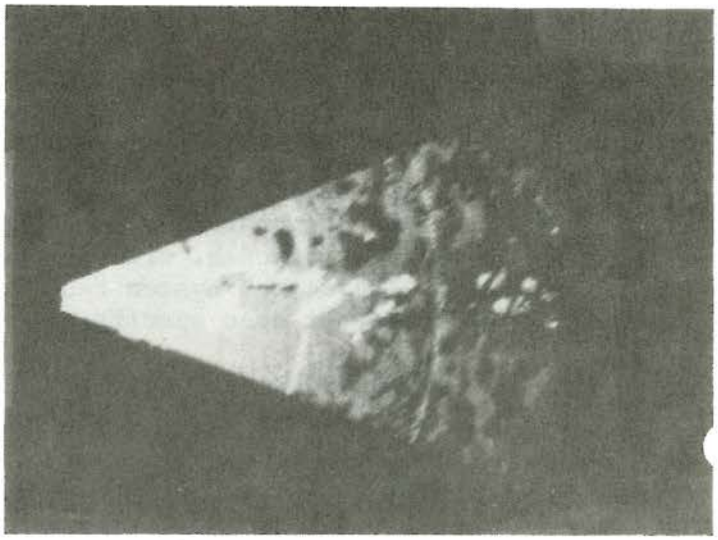

Figure 1b. Scranton-Wilkes Barre, Pa.
(LaGrange Polynomial Data
Compression-7,000 Feet)

The NAVTRADEVCEN base-line system is configured in such a manner that a non-real-time software simulation of a DRLMS is performed on a general-purpose Sigma 7 computer; and the results, the simulated radar displays, are then displayed on a CRT in real-time via special-purpose interface hardware. This is equivalent to observing preflown missions. This special-purpose interface hardware and display, constructed in-house, is shown in figure 2. The data base used for these studies consists of a 60 x 270-mile area of northern Pennsylvania (i.e., the Warren, Williamsport, Scranton USGS maps). The terrain data for this area was obtained from U.S. Army Topographic Command. The reflectance data for the same area was obtained by digitizing 250,000 U.S. Geological Survey maps. The base-line system utilizes no data compression techniques, or other computational shortcuts so that the displays generated will be best possible for the available data. The programing of both the base-line system and the software simulation of a DRLMS is written in Fortran to provide a high degree of flexibility for experimentation.

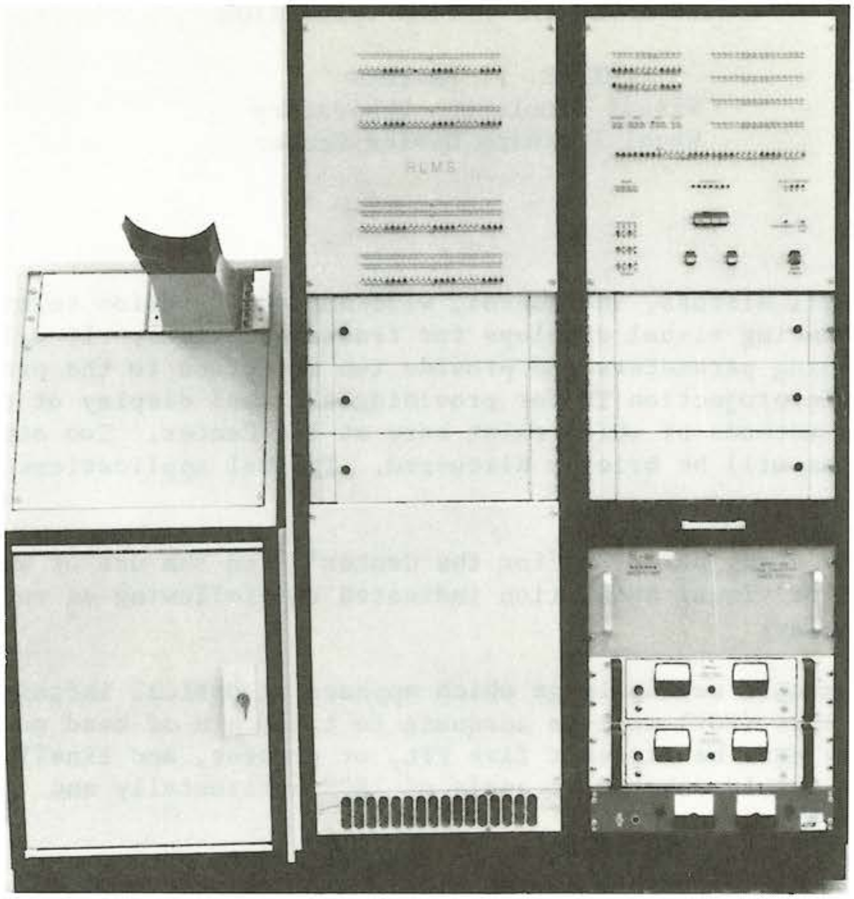

Figure 2. RLMS Interface and Display Hardware

CONCLUSIONS

The digital approach to radar landmass simulation is the approach of the present and the future. Digital radar landmass simulators will have the flexibility to provide easy updates of the data base and simpler maintenance. DRLMS also provides for the use of a single data base by many independent trainee stations. The technological advances of the past few years have made digital radar landmass simulators possible, but there is much work to be done before they will be fleet operational.

WIDE-ANGLE PROJECTION TELEVISION

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INTRODUCTION

This paper will discuss, in general, wide-angle projection television as a tool for producing visual displays for training devices. It will describe the defining parameters and provide two solutions to the problem of using wide-angle projection TV for providing a visual display of the real world - both methods of which exist here at the Center. Two other potential solutions will be briefly discussed. Typical applications will be offered.

A feasibility study performed for the Center(1) on the use of wide-angle television for visual simulation indicated the following as requirements for the display:

1. Observer should see an image which appears at optical infinity, and
2. Field of View (FOV) must be adequate to take care of head motion, and
3. Brightness must be at least five FTL, or greater, and finally
4. The image should subtend an angle of 180° horizontally and 90° vertically.

The study went on to say that it is known that the eyes are accommodated at infinity, when seeing objects at 100 ft, or more, and a simulated display should present an image at infinity.

A second, more recent study(2), agreed that a scene focused at infinity, was one focused at 50 feet. The study further found that an image at 10 feet distance cannot be distinguished from one at infinity if:

1. It is displayed on a screen of sufficiently large angle, and
2. if there are not connecting structures between the observer and the screen to give distant cues.

The second study verifies that the requirements for a viewing system, for simulation of the real world, be at least 10 feet distance and that the highlight brightness be five Foot Candle Lambert (FTL) or more. With these definitions, the requirements have been set forth on using television for simulation of the real world in a visual display.

Two methods for generating a visual display which allows the simulated scene to appear distant are:

1. through the use of a CRT projector, forming an image on a diffusing screen forming a portion of a sphere with a radius of feet or more, or
2. a smaller image can be made to appear at infinity by interposing a lens between the viewer and the screen. The focal length of this lens should be equal to the distance between the screen and the lens.

   This system, of course, is the virtual image. There is some disagreement with the findings of these studies. It has been suggested that 20 feet should be the minimum distance from observer to image. Also, with the virtual image, large liquid lenses are now available up to 100 inches - so the confinements to small images no longer exist.

SYSTEM

A typical wide-angle projection system includes all the subsystems shown:

Image - Optics - Sensor - Processor - Projector - Optics - Display

The result of the system is the display, which is partially defined with a minimum of four parameters:

1. Brightness or the level of luminance reaching the eyes.
2. Resolution or TV limiting response lines or optical line pairs.
3. Contrast or the ratio of the object to surrounding brightness
4. Visual Acuity or the resolution expressed in terms of the human response characteristics - usually minutes of arc. These parameters define a monochrome system. Additional characteristics would be required to define a color display.

SOLUTION

CRT PROJECTION. The first solution to a wide-angle TV presentation is to parallel three separate systems. Each projector displays a segment of the total display. The existing system uses three 5AZP4 projection tubes with the following characteristics:

Second Anode Voltage	40 Kv
Focus, or G3	8 Kv
Spot Size	7.8 mils
Resolution	750 lines
Brightness	1400 FTL

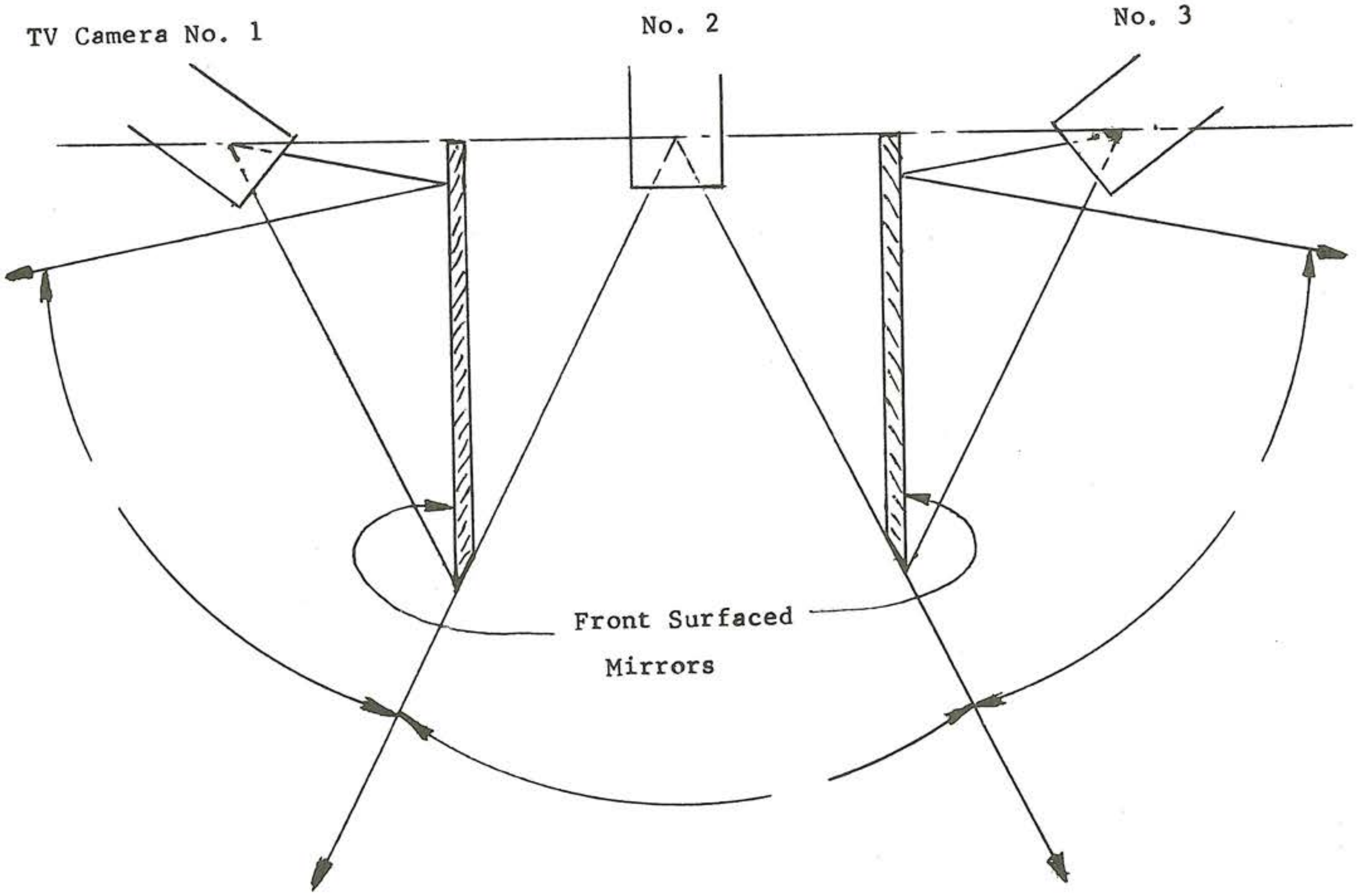
at 250 Beam Current
for 9.5 sq. in. faceplate

The three projectors are mounted 9 inches above the optical center of a 10-foot radius spherical screen at an angle of 21°. Each projector provides a 53° x 53° FOV. This provides a displayed area of approximately 300 square feet. System measurements of the visual display utilizing a screen with a gain of 2.3 are as follows, per channel:

Brightness, approx.	1.0 FTL
Resolution, Horizontal	450 TV lines
Vertical	500 TV lines
Visual Acuity	14.2'/line pair
Scan Rate	875 lines per frame
Video Bandwidth	20 mhz ± 3db

A novel feature of this total system, as currently used, is the pickup camera probe(3). Designed after Douglas(4) work, the optics is a reflective three-channel system using f/1.5, 9mm Kinoptik Apochromat lenses as shown in figure 1. Each camera images a 53° FOV.

The front surfaced mirrors image 53° FOV's. A comparison of this new and the replaced lens system, on a relative performance basis, indicates: a 3 V differential in target voltage produced a 31:1 change in P-P video on the f/1.5 system, as compared to a 6 V differential for a 5:1 change.



Vertical FOV = 53°

Figure 1. Ray Trace View - New Optical Probe

The replaced lens was limited to 65 V P-P video, compared to over 180V on the commercial system (figures 2, 3). The mirror channels reduced the video levels by the predicted 50%. The disadvantages of the CRT projection system are:

1. The seams may be objectionable. The introduction of the transition lines between segments of the display may detract from a trainees decision, or provide visual cues not available in the non-simulated vehicle.

2. The brightness is low. This level (1 FTC) is the minimum required to produce the gray scale.

Light Valve Projector. The second solution, in the use of wide-angle television, to produce a visual display is the light valve. In the Center's application the Eidophor will be referenced, because it is used in an in-house task, although other light valve systems will be mentioned later as potentially excellent solutions. The system operates with the use of a control layer. The elementary control layer principle is shown in figure 4. A 0.1mm thick layer of viscous oil, almost totally nonconductive, is spread on a metallized mirror. Electro-static charges cause deformation of the oil layer allowing light to pass through the Schlierren lens. If the electron spot on the oil layer is of such a size that the scanned lines are sufficiently wide to touch

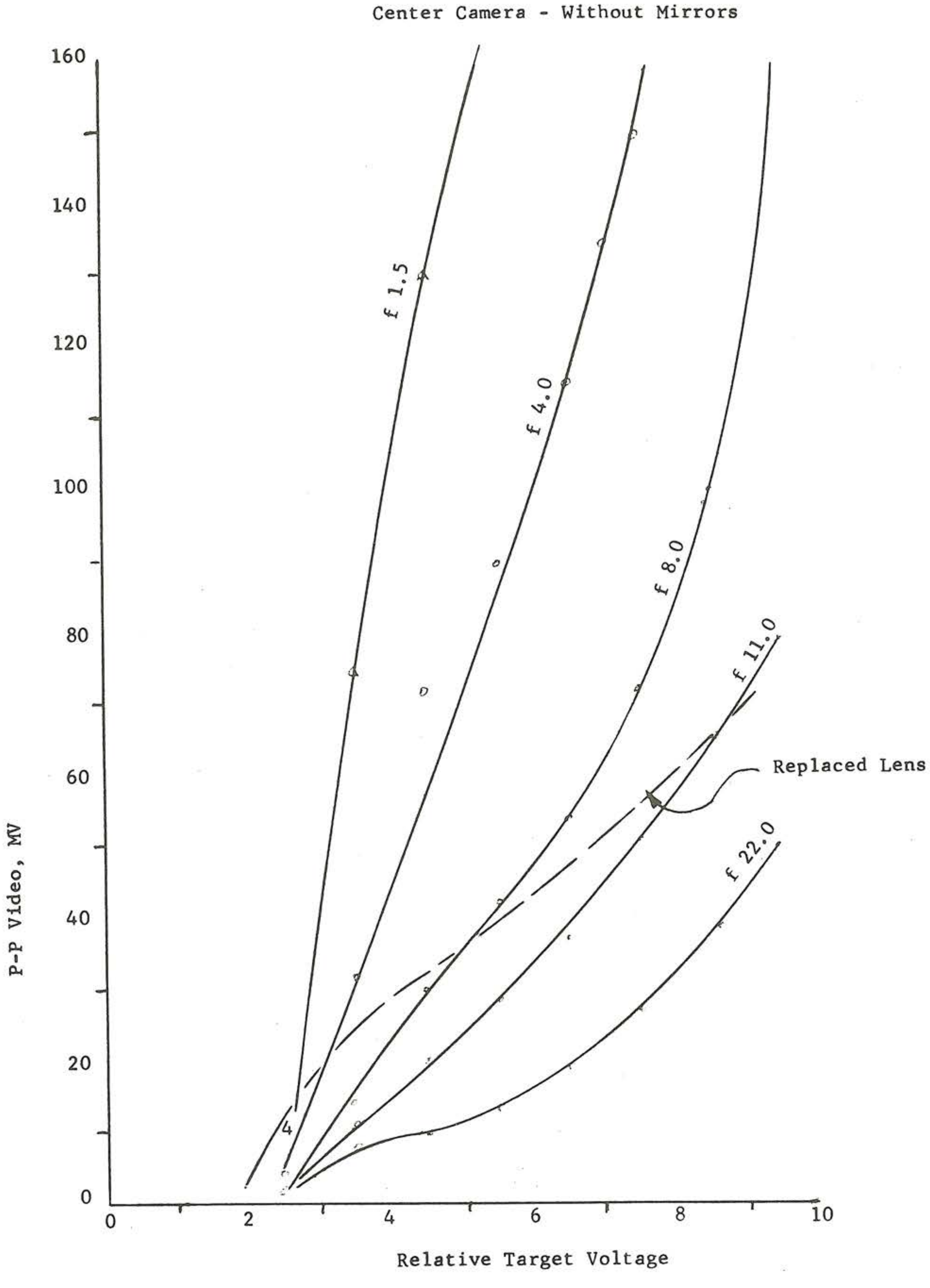


Figure 2. Relative Video Output

Outside Camera - With Mirror

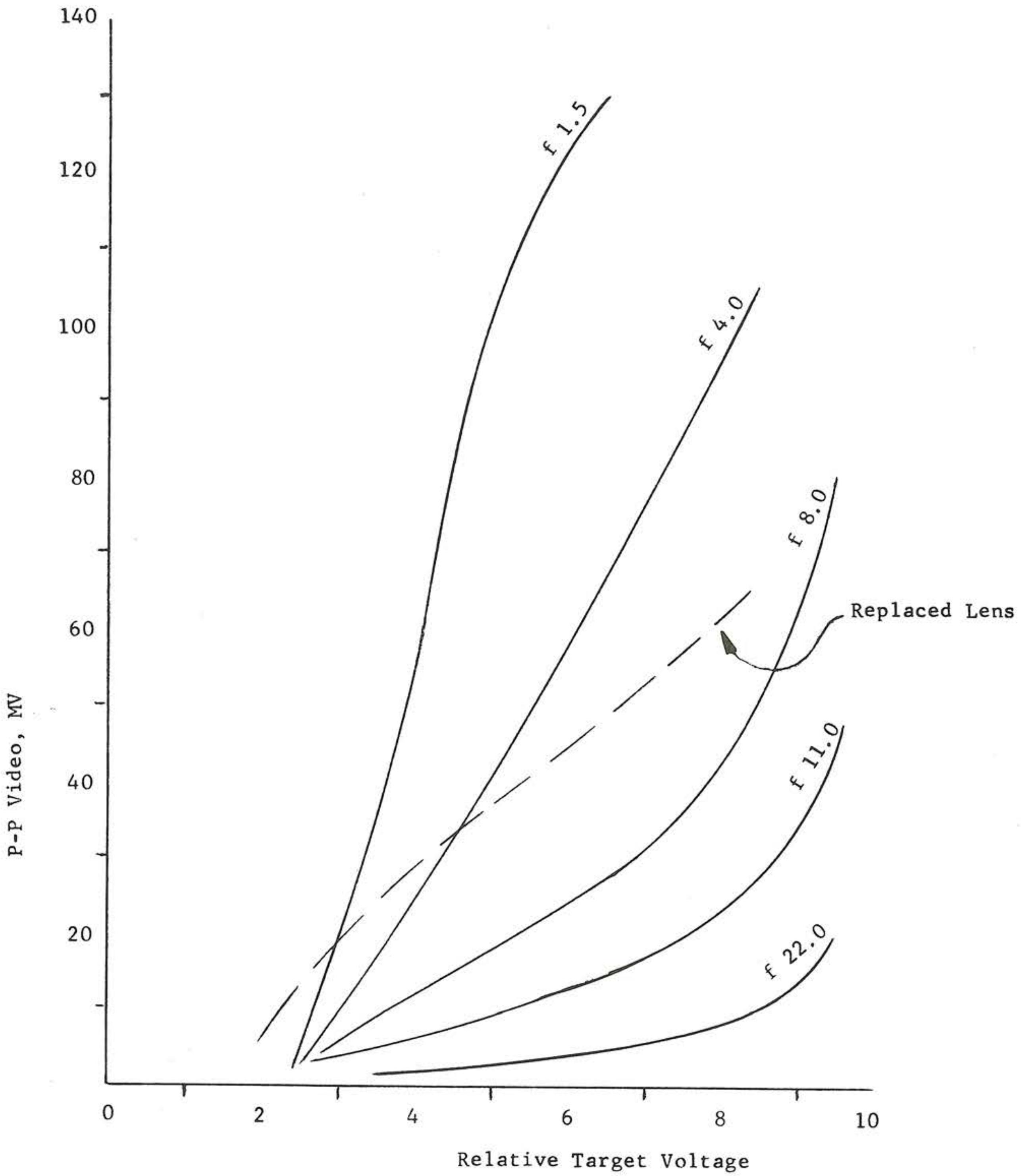


Figure 3. Relative Video Output

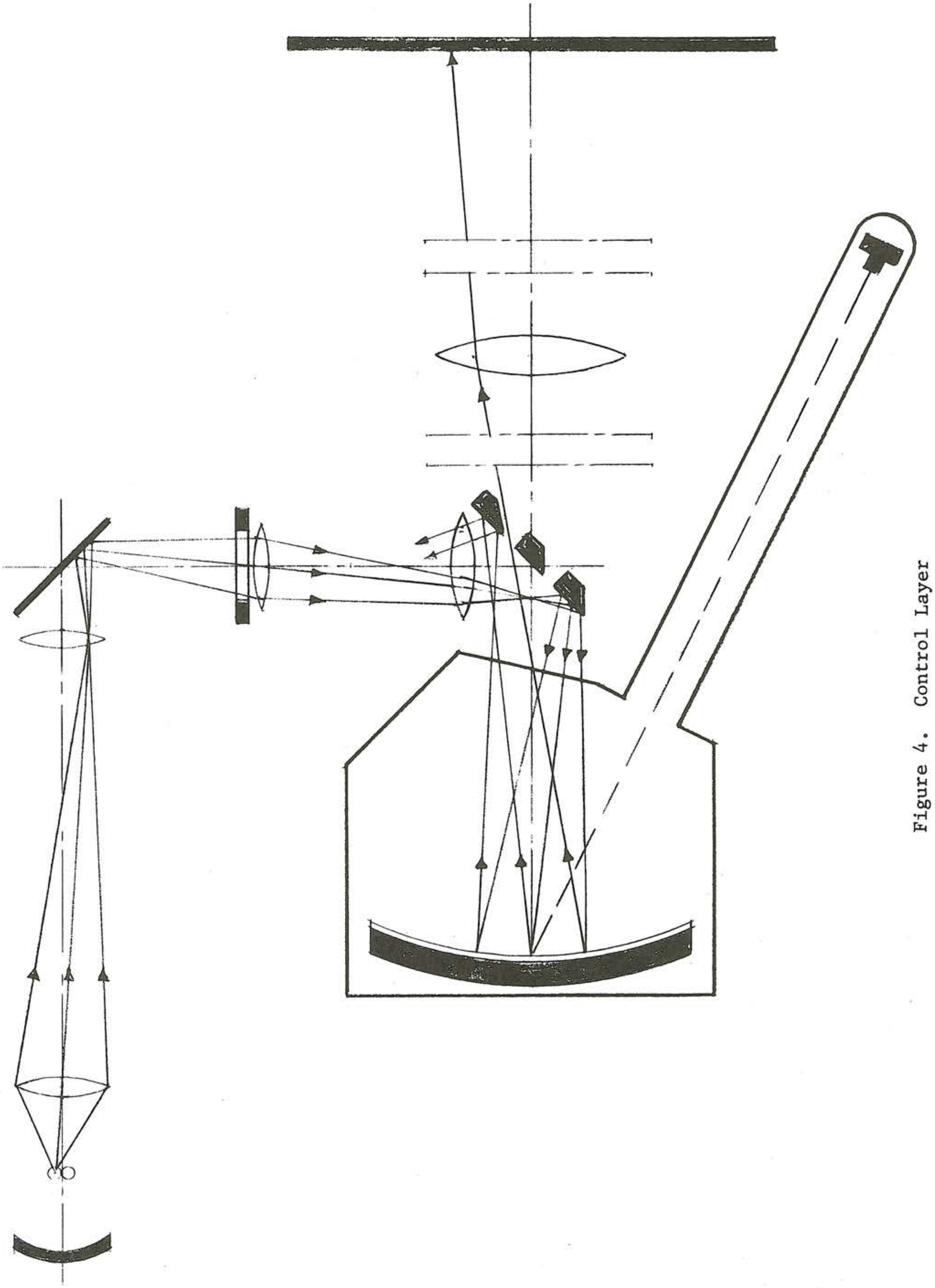


Figure 4. Control Layer

along their length, the charge will be distributed evenly over the whole layer. This layer is, therefore, subjected to a constant pressure over the entire scanning area and thus remains smooth. In this case the screen remains dark. If the electron spot is reduced in size, so that adjacent lines no longer touch, there is a charge-free space between the lines. As a result, the pressure distribution assumes a pattern of linear structure that produces a deformation of the oil surface, and thus the reflected off angle light passes through the bars. Variances are obtained by changing the size of the electron spot - with the video information. The EP-4 unit in the lab is defined as follows:

Light Source, Xenon Lamp	1600 W
Light Output, Open gate	2025 Lumens
Illumination Uniformity	68%
Contrast Ratio	166:1

The in-house light valve has been subjected to a visual test to determine its capability in limiting resolution. Bypassing the video amplifier, 1600 horizontal TV lines have been projected. With the existing video amplifier and a wide band camera (32 mhz) 1100 TV lines were displayed.

Because the system was obtained to develop and study a high brightness wide-angle display, it was necessary to obtain custom optics to perform the task. A set of matching lenses, camera and projection were designed, constructed and tested to match the system by an outside optical contractor. The matched lens pair are anamorphic and provide a 60° vertical by 160° horizontal FOV.

The camera lens is 1/5.66th scale of the other. The characteristics of the lenses are:

Relative aperature, variable		f/5.6 nominal	
		H	V
Effective focal length,	camera	4.4	8.2 mm
	projection	24.5	46.2
Back focal length,	camera	71.5 mm	
	projection	377 mm	
Relative Illumination		65%	100%
Resolution, f/8	camera	200 l/mm	
	projection	28.5 l/mm	

The camera lens is variable in focus. The lens were measured with a 200 KC target and an aperature of f/5.6 and found to provide a depth of field of 6" + 18'. Geometric distortion in the camera lens, caused by the anamorphic elements, (different magnification in the horizontal and vertical planes) strictly cancels in the projection lens. The Physical Science Laboratories (5) measurements are shown in figure 5. The light valve again was mounted with its lens 9 inches above the optical center at an angle of 21° in a 10-foot radius spherical screen. Measurements taken on the assembled system indicate —

Highlight Brightness (SG = 2.5)	10 FTL
Resolution, limiated by input system	H 400 lines
	V 700 lines
Visual Acuity	27'/line pair

Improved cameras are on order which will provide 1500 lines horizontal resolution.

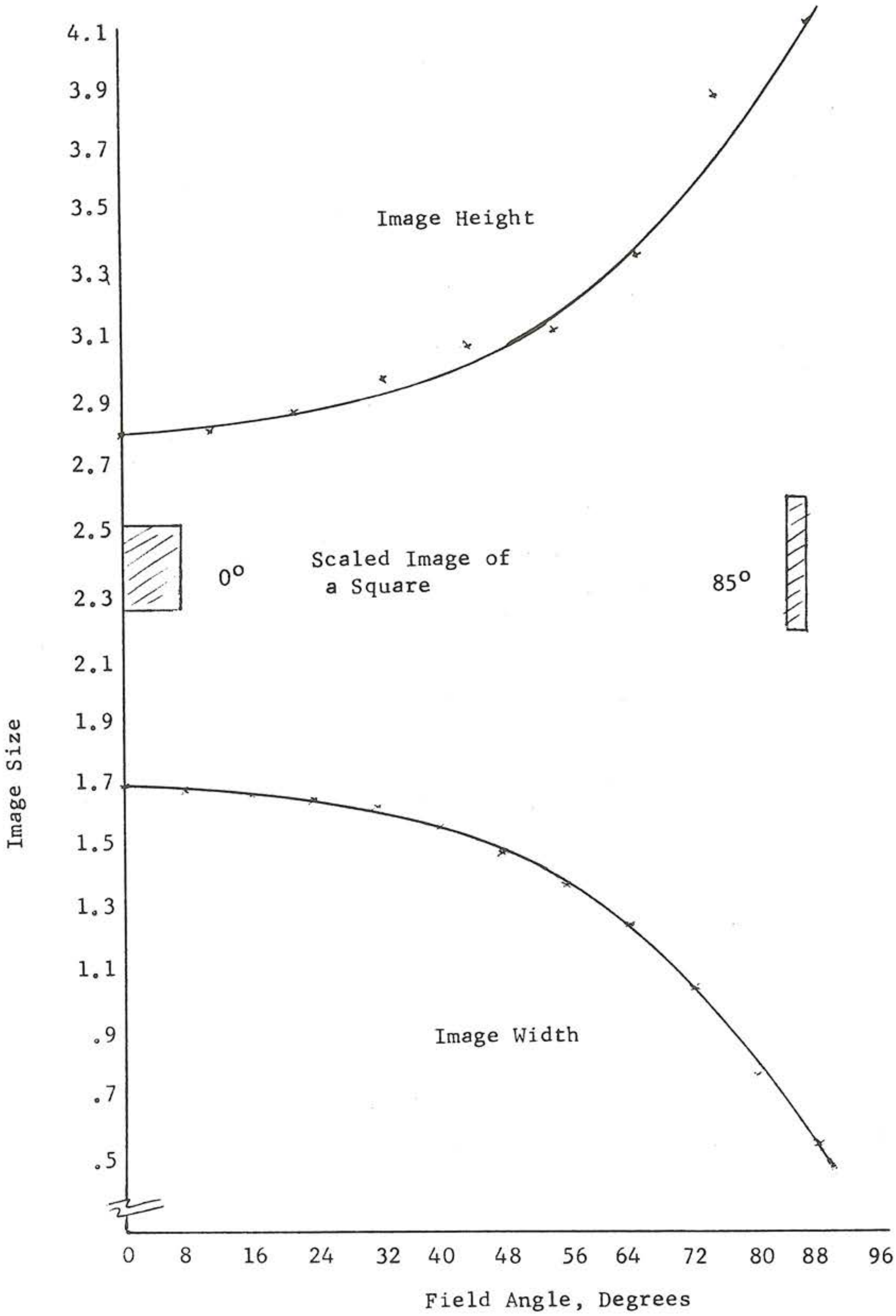


Figure 5. Image Size vs Projection Field Angle

The 400 lines horizontal resolution are highly deficient in providing a display for effective training. In fact, the projected image is barely legible. In excess of 1000 TV lines are required to be comparable to the three CRT projector system. One thousand five hundred TV lines would be required.