NAVTRADEVCEN IH-206

PROCEEDINGS OF THE FIFTH NAVAL TRAINING DEVICE CENTER AND INDUSTRY CONFERENCE

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Proceedings of the Fifth Naval Training Device Center and Industry Conference

ABSTRACT

A compilation of papers on a variety of technical and training subjects relating to training device technology and training methodology. These papers were presented at the Fifth Naval Training Device Center and Industry Conference held at the Contemporary Hotel, Walt Disney World, Orlando, Florida, February 15-17, 1972.

The conference theme "Twenty-five Years of Training Simulation—Springboard for the Future," provided a common ground for the exchange of new ideas and discussion of mutual problems. This fifth conference is part of a continuing program to encourage and develop better liaison between the Naval Training Device Center and the training simulation industry.

FOREWORD

During the past twenty-five years the Naval Training Device Center, together with the training device industry, has developed a continuously advancing training simulation technology to meet the ever expanding training needs for the warfare areas of the Navy, the Army, and the Marine Corps.

As the Naval Training Device Center goes into its second quarter of a century of partnership with the training device industry, the need for an acceleration in the advancement of training technology becomes more and more pressing. We are sure that the achievements of the past twenty-five years form a good basis for industry's and our own future endeavors to meet the demands of the user, and that these achievements justify the theme for this year's conference—"Twenty-five Years of Training Simulation—Springboard for the Future".

As in the past conferences, much can, and will be accomplished if frank and open discussion continues. By the exchange of ideas and active participation in efforts of common interest, industry can greatly contribute to achieving the goals placed on the Naval Training Device Center, and the U.S. Army Training Device Agency by the combat forces of the Navy, the Marine Corps, and the Army.

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TABLE OF CONTENTS

SESSION II (continued)

SESSION III

SESSION IV

SESSION IV (continued)

SESSION V

SESSION VI

PAPERS PUBLISHED, BUT NOT PRESENTED

CONFERENCE THEME

DR. H. H. WOLFF
Technical Director, Naval Training Device Center and
Conference General Chairman

Military training is as old as organized society. For many centuries, it was conducted in the real environment using real military hardware. Gradually, however, mainly in the first quarter of this century simulation was introduced. For example, special exercise ammunition was developed and the new weapons platform, the tank, was simulated.

The years between the two world wars and especially World War II itself brought a basic change in military training. It was in that period that our Navy started to replace training in the real environment by training in a simulated environment, by means of training devices, and training device technology and training methodology started to develop into a science and a technique.

We, here at the Naval Training Device Center, had, last year, the pleasure of commemorating the 30th year of the Navy's Training Device involvement, and the 25th Anniversary of the establishment of the first specialized Training Materiel Command.

The increase in complexity of modern warfare, especially multiplatform warfare, and the resultant need for training in simulated multiplatform settings resulted in the need for a vast variety of training programs to train for the many different skills needed in modern warfare. Naturally, this large variety of training problems caused a large variety of training activities to get involved in different aspects of the Navy's training needs and resulted in a fragmentation of the Navy's training program. It became more and more obvious that a coordination and unification of all these various training programs was mandatory if the Navy wanted to achieve the highest quality of training. This demand has led the Chief of Naval Operations to reorganize the Navy's training efforts by placing all training other than that assigned to the Fleet Commanders and the Chief, Bureau of Medicine and Surgery, under the newly established Office of Chief of Naval Training.

This reorganization will make it possible not only to provide an all encompassing and more effective unified training program for all of the Navy's present and future warfare situations, but will also achieve through cross-fertilization between different training areas a vastly improved training program and thereby an improvement in the professional capabilities of all Navy personnel.

Those of you who have been associated with military training, since the establishment of this organization, or even have been associated earlier with the initial phases of synthetic training, when RADM (then CDR) Luis de Florez became the first deskholder for training material in the Navy, know that training material has come a long way since the days of the 610 H Street NE Washington garage.

Starting with simple straight forward technology, we have reached today a point when even the most advanced technology available does no longer satisfy the needs of the Navy's training activities.

Operational equipment is getting increasingly complex. Its operation requires more and higher skill. And, consequently training devices call for higher and higher sophistication.

As most of you know, the Naval Training Device Center, and the training device industry have — during the last decade — made vigorous attacks on the state-of-the-art in training device technology, especially in the areas of visual environment simulation and in radar and sonar training simulation.

In spite of many achievements of the past, many areas of training device technology, especially systems for flight and ship control training, for sonar and radar for team and for task force training, to name a few, call for further advances, if we want to achieve training that is cost-effective as compared to training in the real environment, if we want to achieve the training goals in the shortest amount of time, and if we want to achieve these goals with equipment that minimizes the cradle to grave overall cost, and that minimizes the human resources needed for its operation and its maintenance.

The problems that existed six years ago made us aware of the fact that a closer cooperation between NAVTRADEVCEN and industry was needed. They have led to the first NAVTRADEVCEN/Industry Conference, which Captain Jack Sloatman, who was at that time our Commanding Officer, personally vivaciously promoted.

We open today the Fifth NAVTRADEVCEN/Industry Conference under the Command of Captain Frank Featherston, who was the driving force for having this Anniversary Conference here in Walt Disney World. As you may know, conferences of this type; especially, in today's financial environment —require high-level approval which can be obtained only if the Command is wholeheartedly promoting it, and all of us at NAVTRADEVCEN are very happy that Captain Featherston could convince our parent Command of the importance of our NAVTRADEVCEN/Industry Conferences for a continued progress in the support of the Navy's training program.

Looking back over the years that have passed since our first conference we find that many advances have been made during this time span.

In our first conference, I talked to you about our concern over the extensive cost and time spent for the reliability test of one-of-a-kind training devices and proposed new approaches to cope with this problem. Several of our reliability people have attacked this problem since then as most of you know with considerable success. For, whereas five years ago we required a test time of approximately 250 hours, with a possibility of running up to close to 500 hours, today we can often satisfy our reliability conscience in a 40-hour test. Five years ago we tested under an unrealistic continuous operation. Today, we go through a realistic operational cycle, and have begun to operate the equipment under test in accordance with a realistic lesson plan such that the test corresponds as much as possible to the actual usage. Five years ago we did not distinguish failures as to their criticality in the training program. Today, we assign weights to failures and provide thereby a much better basis for a meaningful reliability acceptance test.

In the 1967 conference we discussed the importance of the value engineering program. With the cooperation of the industry, we have achieved considerable annual savings for the Government and thereby the taxpayer. During the last fiscal year, for example, $659,000 were saved under this program.

In the 1967 conference I mentioned to you also the need for automatic failure indicator systems. Unfortunately, I cannot report here any significant progress. This is, therefore, a call for investigations into how to take advantage of the state-of-the-art in automatic failure indicators, and automatic testing, and for a possible promotion of the state-of-the-art where it is needed, certainly good fields for industry's Independent R&D Program.

Finally, I had asked, in our 1967 conference, to pay more attention to the instructor and trainee problem in the development of training devices, rather than to be satisfied simply with the simulation of operational equipment.

I renewed this request in our 1968 conference, asking especially to strive for an improvement in the student to instructor ratio. Industry has responded to this need.

For, we have meanwhile procured and are presently under new procurements for training devices in which the instructor is enabled to handle several students simultaneously, both through an automatic adaptation of the difficulty of the training task to the trainee's performance and through the use of cathode ray tubes for on-call displays of instruments and performance parameters. You will find these concepts increasingly called out in the specifications for future flight trainers and others.

In the 1968 conference, in addition to the repeated request for automatic failure indicators, I asked for self-healing systems. This again should be a good problem for industry's independent R&D Program, especially for companies that are also involved in the space program.

In our 1969 conference we talked about a diversity of problems, problems in training psychology, trainer technology and trainer procurement, many of which are still unresolved; especially the automatic evaluation of student performance, adaptation steps in adaptive systems, physiological factors in training (a very broad field), the various areas of visual simulation, such as computer-generated displays, for example radar displays, as well as many others, still pose problems.

For several years we have tried to reduce training device cost, maintenance cost, spare parts inventory and maintenance skill requirements by an aggressive standardization program. I would like to take this opportunity to acknowledge the contributions that our industry has made to this effort, especially through the sub-committee on training device component/equipment standardization of the National Security Industrial Association.

As a result of our standardization effort the number of waivers for non-standard parts has tremendously decreased, offeror's standardization efforts are evaluated as to their compliance with standardization plans such as the MIL-T-23991 specification, the NAVAIR Avionics preferred standard test equipment list and others.

Very shortly a cockpit procedures trainer procurement will be used to evaluate the applicability of the Navy's standard hardware program to training devices, and in the next fiscal year we intend to specify the use of SHP (Standard Hardware Program) modules for a major training device, just to mention a few of our plans to promote standardization.

Let me turn now to a few problems that have not yet been brought to the forefront.

The need to replace more actual flight time by training device time has resulted in a demand for flight trainers of more encompassing simulation features, trainers that provide both motion and visual environment simulation. Since a motion platform can provide only a limited motion simulation; namely, an acceleration and a deceleration onset, a wash-out has to be provided. As a consequence of this, any motion platform position may represent different operational platform (for example aircraft) positions, each of which demands a different visual presentation of the visual environment. The difference in the limitations of motion simulation and visual simulation prevent a perfect solution for the linkage between motion and visual display. We will have to be satisfied with a deficiency minimization. Though some experiments have been conducted in this field much more knowledge is required about the motion inputs that different vehicles provide to the human sensory system and for which we have to provide motion simulation. A multidisciplinary R&D effort is needed here before we have the technology well enough in hand to avoid negative training and satisfy the user.

Maintenance training was for many years a simple device problem. Operational equipment was cut apart and provided the hardware needed by the instructor for his lecture. With increasing complexity of operational equipment to be maintained, maintenance training cannot be effectively undertaken any more by using operational hardware. Very little effort has been directed towards increasing the training effectiveness in this area by better maintenance training devices. A few new approaches are reflected in the new generalized sonar maintenance trainers which we procured for the school in Memphis. The Chief of Naval Training, and the Chief of Naval Technical Training are looking at us and at the trainer industry to provide the means for vastly improved maintenance training material.

All of us know that in spite of the many advances that have been made we are still behind the demands of the users. These demands have increased in sophistication faster than the state-of-the-art progressed. This holds true as much for training methodology as it does for hardware, especially for totally integrated multiunit task force systems.

Today's operational systems offer such a tremendous versatility of utilization that only extremely well-trained personnel are able to fully utilize the system capability. This means that the training programs have to be very carefully developed and standardized to assure the use of the most effective training methodology.

In future larger procurements--especially of weapons systems trainers--you will find, therefore, increasingly that a detailed course outline and a training syllabus are mandatory deliverable items.

Let me take up another subject which we should vigorously attack.

We have about 550 million dollars worth of training devices in the Navy inventory and it has been estimated that we have in the training program close to two billion dollars worth of operational equipment that has been set aside for training purposes. Assuming that this operational equipment will have to be replaced over a 10-year span, about 200 million dollars will be spent annually for such equipment. You can analyze for yourself how much of this equipment could be replaced by training devices that are more training effective and far less costly, and how much the training device market could broaden and how much taxpayer's money could be saved if all of us would take steps to build-up this area more aggressively.

As you can readily see, much has been achieved in the last 25 years, much more is ahead of us, only part of which I could outline to you. But based on these past achievements, both within NAVTRADEVCEN and in Industry, we feel that our first 25 years in the training device business form an excellent springboard for the future.

As you know, NAVTRADEVCEN is a multiservice activity for we not only serve the Navy, but also the Army through the U.S. Army Training Device Agency under Colonel Mierswa, and the Marine Corps, that through Colonel John Terry, the Marine Corps Liaison Officer, is rapidly increasing its training device involvement. Finally, we often have the privilege to assist the Air Force in meeting its training device requirements.

I am very happy to welcome all our friends from the Navy, the Army, the Marine Corps, and the Air Force, and last, but not least, from our industry.

WHAT'S HAPPENING IN TODAY'S ARMY

General Ralph E. Haines, Jr.
Commanding General, U.S. Continental Army Command
Fort Monroe, Virginia

I'm happy to be here on the Silver Anniversary of the Naval Training Device Center and gratified that this conference offers the opportunity for the services and industry to focus attention on the past 25 years of training simulation as a springboard for the future.

In acknowledging the 25th Anniversary of the Naval Training Device Center, I am pleased to note that this has been a cooperative effort with the Army participating for the last 21 years. The Army is appreciative for the excellent support that has been provided our training during this time. You are to be commended for your fine work.

My purpose here today is to tell you "What's Happening in Today's Army"—with particular reference to the innovations in the Army's training programs, and later in my discussion pass on to you information concerning the Modern Volunteer Army Program.

First, I would like to say that the Continental Army Command (CONARC), with its 13 training centers, at which newly recruited or drafted soldiers receive their initial training, and the 24 Army Schools, which train and educate officers and enlisted men to various levels of skill or knowledge, has the largest training responsibility of any U.S. Command world-wide. At the end of FY 71, there were nearly 367,000 individuals trained in Basic Combat Training (BCT), 291,000 in Advanced Individual Training (AIT), and 271,000 in the service schools, for a total of 928,000. So you can see CONARC's mission as the Army trainer is sizeable. CONARC is responsible for determining training aids and device requirements, and operating the CONUS training aid center system. The Training Centers and Army Schools, which constitute the "training base", and the major users of training devices, today faces a dichotomy of effort deriving from the necessity to reorient our training toward requirements in other parts of the world, and yet continue to provide maximum support to Vietnam. The country is psychologically in a post-war period even though we are still heavily involved in a shooting war. Our training dollars have been decreased by budget constraints, with no reduction in mission, to maintain a high-level of combat readiness. As a result, a great deal of command emphasis from the Chief of Staff of the Army, down through major commands, is being exerted to make maximum use of training devices in lieu of the actual weapon or item of equipment where effective training can be accomplished, and cost savings accrued.

Our primary aim must be the effective discharge of our responsibilities for the defense of our country. By that, I mean that we train in the skills that relate directly to military duties and employ all means provided by science and industry toward the accomplishment of this training.

Our training programs are under continuous review, revision, and refinement. We place high priority on keeping them current and attuned to changing needs. The objective is to assure that these programs remain vigorous and challenging for our young soldiers.

At our 13 U.S. Army Training Centers, each inductee entering the Army receives an eight-week Basic Training Course covering the military fundamentals that all trainees must have. Upon completion of basic training, about 70% of the trainees remain in the Training Center System for eight or more additional weeks, and receive Advanced Individual Training or AIT in one of the 69 military skills taught in that system. Another 20% of the basic training graduates proceed to Army Schools for AIT in one of approximately 178 skill-producing courses, the longest of which takes a full year to complete. The remaining 10% of basic training graduates go directly to units to complete their skill qualification by on-the-job apprentice-type training, or to a duty position for which they are already qualified by reason of their civilian education or experience.

We are making changes in AIT with increasing emphasis on hands-on training and performance testing.

The content and nature of Army education and training is, I contend, scientific, because it applies "expert knowledge and technical skill" in its theory and in its practice. But, we also attempt to apply scientific methods in the accomplishment of this training. The Army's interest in training technology stems from the need to improve training, and produce a more skilled soldier in less time and at a lower cost. Several years ago, we decided that the base process upon which our training must be developed is the systems approach. After thorough study and preparation, we established a five-year program through which all courses at our Army Schools and Training Centers will be systems engineered.

In this process, the first and most important step is job analysis, which identifies the on-the-job performance requirements in terms of individual tasks and characteristics of various duty positions. During job analysis, our schools conduct interviews with job incumbents and use the output of the military occupational data bank, which is a computerized repository of detailed job and task data collected from questionnaires administered on an Army-wide basis. These data indicate job frequency and help determine what training is required. In the second step of systems engineering, essential tasks are selected for training and then are evaluated to determine whether they should be taught in a formal course of instruction or accomplished by on-the-job training. In succeeding steps, tasks are converted into training objectives and training materials to include training aids and device requirements and tests are prepared. Quality control is the last step of the process. Test results are analyzed and feedback information is obtained by observation and reports from commanders and course graduates. By these means, courses are continually evaluated and updated.

The systems engineering approach to training is fundamental to insuring that course content and training methods develop soldiers who can perform successfully on the job. The systems approach is also the vehicle for capitalizing upon the advantages of other training innovations, as it guarantees that all of them receive full consideration in course design and development.

As a matter of information, CONARC uses programmed instruction throughout the Army School system. This is a self-paced method of teaching through the use of specially prepared texts which provide instant feedback to the student and thus assures progress at his individual rate. Our analysis of programmed instruction has shown that most students, who have difficulty learning from a classroom instructor, are better able to absorb and retain knowledge through texts.

A natural extension of the use of programmed texts in particular segments of instruction is their use in completely self-paced courses. Our Helicopter Instrument Flight Course has been completely converted to self-paced instruction by allowing students to progress at their own rate instead of in lock step. An average savings of two weeks in training time was achieved; additionally the dollar savings accrued were sufficient to amortize the total contract cost by the end of the first year of operation.

Presently, the Army has a number of training programs that utilize computer-supported instruction. Based on our experience, we have found that the computer can be a most valuable tool in both the active instructional process as well as in the administration and management areas. CONARC exercises a progressive development policy, which encourages investigation, into discrete applications of the computer in support of training functions.

A final example of our educational innovations is our extensive use of Educational Television, or ETV. Closed circuit educational television is used at all 24 of our Army Schools and 10 of our Training Centers, with taped material ranging from basic training subjects to complex military problems.

We derive many advantages from use of television. We realize significant savings in equipment and manpower costs by taping live performances for repetitive instruction. Other benefits include the ability to standardize instruction and to preserve noteworthy presentations otherwise available to only a few students on a one-time basis.

In addition to producing instructional tapes for television viewing, our television production facilities support the Army-wide training film program. TV tapes are converted to 16mm film for Army-wide distribution. These are but a few highlights of the many changes taking place in the Training Centers and Service School training programs in today's Army.

Now turning for a moment to future developments in the area of training simulation. In the past, the Army has made considerable use of training aids and devices in the Missile, Armor, Infantry, Artillery, and Aviation fields. However, we have scarcely touched on simulation for the Combined Arms Tactical Training Programs. The shrinking land area available for large scale maneuvers, the requirement to improve training effectiveness, and reduce training cost, requires us to look to simulation to solve our most critical tactical training problems. In this respect we have initiated a requirement to develop a Combined Arms Tactical Training Simulator (CATTS). The purpose of the CATTS will be to simulate a variety of combat situations for the training of future commanders and staff officers. The primary requirement is to realistically approximate the placement of a commander and his staff in either of two simulated combat options, a ground command post environment for conduct of tactical ground operations, or a command and control helicopter environment for conduct of airmobile tactical operations. We are looking forward to the simulator as the long-range solution to one of our many training problems. As many of you know, our most prestigious trainer to date is the Synthetic Flight Trainer System now undergoing test at Ft. Rucker. This, the Army's most ambitious and costly trainer development program represents a move from the horse and buggy days and into the space age for instrument flight training. We believe that the future cost savings potential will be very significant not only in flying hours saved, but in better trained aviators.

While any review of the total training devices and training aids picture reveals that many requirements are initiated by the people at the local Training Centers and Schools, I am aware that many are developed by industry or the laboratory, and I am well aware of the part you play in the initiation and development of our requirements. We must always be on the alert for new innovations, new developments, and most of all, new ideas on how to improve the training of our modern Army.

This leads me to another major innovation that is taking place today—that of the Modern Volunteer Army. The Chief of Staff has directed the Army to move without delay to build a more professional Army with a zero draft and to achieve this by 1 July 1973. The program was kicked off officially by General Westmoreland at his Commanders' Conference, 30 November 1970.

The Modern Volunteer Army Program consists, in general terms, of three categories of actions or initiatives, with purposes described as—

Strengthening Professionalism
Improving Attractiveness of Army Life
Enhancing Public Respect for the Soldier.

Inherent in this combination of categories is the will to promote the most effective and efficient means of mission performance; to improve the life-style and living conditions of the soldier and his family, and to enhance the respect of the soldier for himself and in the eyes of the American public. Through accomplishments in each of these areas we are striving to attain the goal of a better Army and eliminate reliance on the draft.

The Modern Volunteer Army (MVA) Program began last November when several high impact actions, such as elimination of reveille, more liberal pass policies, and a shorter work-week were adopted Army-wide. Numerous actions designed to enhance training, improve living and working conditions, and eliminate the non-essential, so that we may get on with the necessary aspects of duties, have since been implemented. Within the context of each of these actions, I want to emphasize that we seek first to build a highly professional, disciplined Army capable of survival and victory on the battlefield.

As an integral part of the MVA Program, test experiments, under the title of Project VOLAR (VOLAR being the acronymn for Volunteer Army), are being conducted at selected Army installations. The purpose of these experiments is to test and determine those improvements or changes which, when implemented Army-wide, will enhance the military posture and increase enlistments and reenlistments. Four CONARC installations took part in the Project VOLAR experiments during FY 71. During FY 72 we are expanding these experiments and a total of 13 Army Posts, within the Continental United States, will be participating.

To achieve our goal of a highly professional volunteer force in FY 73, we must increase enlistments and reenlistments significantly. To assist in accomplishing this, the attractiveness of the service must be increased together with a decided improvement in the Army's combat capabilities.

I am sure that you have seen reports in the local papers of many of the specific measures we are taking in these areas. We have solicited ideas from a broad spectrum of Army personnel and are currently in a testing period, trying out ideas, which we consider have merit. These tests are at selected locations and conducted under carefully controlled conditions. Changes are always difficult, particularly in a stable institution such as the Army, and especially when they impinge upon proven methods. But times are changing; and we must be responsive to social change, without compromising basic values, if we hope to remain in contact with and communicate to the soldiers.

In our efforts to improve the life-style of the soldier and to remove service irritants, we will not impair the ability of the Army to perform its mission. We, in the Continental Army Command, are mindful of our responsibilities and intend to improve the Army's professionalism within the context of the Modern Volunteer Army. This will call for all the talent and judgment at our command.

Regardless of changes we make within the Army, however, we cannot hope to achieve our goals unless we receive support from the Executive Branch of the Government, members of Congress, the news media, and civic, business, and educational leaders.

The goal of acquiring a completely volunteer force is yet to be proven. Certainly we will leave no stone unturned in attaining that goal.

It is important that we keep draft legislation in existence until we can demonstrate conclusively that a Volunteer Army is both feasible and effective in the discharge of its assigned responsibilities. We will, in fact, have a continuing although lessening need for the draft for several years to come. If we are able to shift to a Volunteer Force, we must do it without creating a gap between the Army and the people which we serve. In our zeal to see those laws enacted, that will provide us with the inducements needed to attract sufficient members of qualified men and women, we must not create a mental climate in which the average citizen feels that he can, in effect, buy his way out of any obligation to defend his nation.

We, in the Army, are faced today with the activism of the "now" generation. I recognize that the local draft board is only one of many institutions to which the youth of today cannot relate easily. Many are skeptical of the values of our society and cynical because of inconsistencies found between stated beliefs and actions which appear to belie those beliefs. One of the lessons learned during research, conducted on the fall of the Roman Empire, is that "a society that loses interest in its Army and distains military service will pay for its mistake sooner or later." I feel that the MVA Program will do much to prevent this conditon from developing in this country.

The Vietnam War weighs heavily on most of us. However, my current responsibilities do not encompass that area and I would prefer to leave to the writers of history the rights or wrongs of our involvement there. I must observe, however, that I find it difficult to accept the thesis of some which, through a strange transposition of fact, has made the aggressor the aggrieved. I do have a feeling of compassion for the young men and women, who return from Vietnam, every day in the year. They merit a far better reception than they are getting from the people of this country. Our most pressing job in CONARC today is to rebuild the dignity, pride, and motivation of the post-Vietnam Army. Again, we will need all the talent and judgment we can muster. After every war there has been a tendency toward a drop in morale, esprit, and prestige for the man in uniform. We must work to overcome this tendency because of its deleterious effect on both the man in uniform and the public. The dedication of the soldier and the confidence of people in him are principal ingredients of our national strength. The nation will be the loser, if over the longer term, the dignity and pride of the soldier are not retained.

I have attempted to outline for you some of the aspects of our education and training requirements and to point out the way the Army is moving today. With shrinking resources and maneuver areas, the Army is placing greater reliance on training aids and devices than at any time heretofore. We cannot be satisfied with our present methods of training. We must constantly search for better, more effective and less expensive solutions to our training problems.

SESSION I

Tuesday, 15 February 1972

Chairman: Dr. James J. Regan
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Naval Training Device Center

TRANSFER OF INSTRUMENT TRAINING AND THE SYNTHETIC FLIGHT TRAINING SYSTEM(1)

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INTRODUCTION

The Army's Synthetic Flight Training System (SFTS), Device 2B24, has been referenced in a number of the papers presented here. It is assumed at this point that the reader is generally familiar with overall SFTS design, and the extent to which it incorporates automated training features as well as manual features which can facilitate the conduct of training administered in a non-automated manner. The device is unique in these aspects in the Army's history of training device development.

Army regulations require that newly acquired equipment of the complexity of the SFTS undergo an extensive service test prior to type classification. Type classification is a step necessary to the introduction of such equipment on an Army-wide basis. An important part of service testing involves a determination of the operational suitability of the equipment. In the case of the SFTS, the Human Resources Research Organization's Aviation Division was requested to support the service test, to be conducted by the U.S. Army Test and Evaluation Command, by developing and conducting an SFTS Operational Suitability Test. The test is in progress, and its findings are expected to be released later this fiscal year. The present paper addresses one portion of the SFTS suitability test, that portion dealing specifically with transfer of instrument training from the SFTS to the aircraft.

The fact that the SFTS is unique makes its suitability testing difficult. Since it is not a replacement for existing equipment, and since much of the training possible with it previously has not been possible for the Army, even using operational aircraft, previous approaches to training device suitability testing are inappropriate for the SFTS. A test which failed to build upon the unique features of the device probably would produce evidence of its unsuitability to the Army's requirement. A test which asked of the SFTS no more than is provided by existing Army flight training devices undoubtedly would lead to its rejection on a cost-effectiveness basis. On the other hand, a test which exploited the design-for-training features of the SFTS, with the goal of determining its cost-effectiveness in a training situation, could lead to quite different results.

A three-phase operational suitability test was developed. During Phase I, primary emphasis was placed upon a determination of the workability of the various automatic and semi-automatic training features of the device. During Phase II, a training program was developed which was intended to exploit the

[1]The ideas expressed in this paper are based on research conducted at HumRRO Division No. 6 (Aviation), Fort Rucker, Alabama, under Department of the Army contract; the contents of this paper do not necessarily reflect official opinions or policies of the Department of the Army.

potential of the device in such a manner that developmental hardware deficiencies would have minimum adverse effect upon test results. During the final phase, a transfer of training study was conducted, and a determination was made of the cost-effectiveness of the device in the Army's rotary wing aviator training program. This paper will address only those operational suitability test activities related to a determination of the transfer of instrument training value of the SFTS.

TRAINING PROGRAM DEVELOPMENT

It is generally recognized that the effectiveness of any training program is a joint function of the equipment employed and the manner of its employment. In addition to having a number of unique training features, the SFTS is significantly more comprehensive in its simulation of the training aircraft than is any known equipment used in undergraduate level flight training. Consequently, a training program had to be developed to take advantage of the capabilities it provided with an undergraduate trainee population. That program was developed during Phase II of the SFTS Operational Suitability Test.

The training program was an advanced adaptation of a program previously developed for use with a fixed wing instrument training device. The fixed wing program is described elsewhere and should be referred to by anyone with an interest in the technology of training applied to flight training per se.[(2)] The primary features of the training program developed for the SFTS are:

—conduct of all training within a functional context

—conduct of all training on a proficiency basis

—specification of all training goals in objective, measurable terms

—conduct of all training in the SFTS, not the aircraft

—treatment of the SFTS as an aircraft

—complete individualization of instruction

—redefinition of the role of the instructor pilot

—conduct of crew training

—use of incentive awards

—use of diagnostic progress rides

—use of all features of the SFTS found workable during Phase I.

Time did not permit a pilot study to verify that the SFTS training program had been optimized from the standpoint of efficiency. The overall Service Test schedule required that student training be initiated as soon as practical. Consequently, the program was evolved largely from experience obtained with the

[2] Caro, Paul W. "An Innovative Instrument Flight Training Program." Paper No. 710480. Society of Automotive Engineers, New York, N.Y., May, 1971.

fixed wing program previously mentioned, with several earlier rotary wing training research programs, the experience of other training organizations, and the general technology of training. The experiences of several commercial airlines were particularly helpful in this regard. As a result, the conduct of student training with the SFTS, Phase III of the Operational Suitability Test, was undertaken with high confidence.

THE TRANSFER OF TRAINING STUDY

EXISTING TRAINING. At the time of the study reported here, Army undergraduate pilot training consisted of four phases—Primary, Instruments, Advanced Contact, and Tactics. The Primary Phase consisted of 110 hours of dual instruction and solo practice in a light, reciprocating engine helicopter, the TH-55. Sixty hours instrument training in a similar aircraft, the TH-13T, plus approximately 26 hours training in an existing instrument training device, a modified 1-CA-1, made up the Instrument Phase. The Advanced Contact Phase consisted of 25 hours transition training in the turbine powered UH-1B, D, or H model helicopter. The final phase of training, the Tactics Phase, consisted of 25 hours training in the UH-1 aircraft. The UH-1 is the primary operational aircraft for the newly graduated Army aviator. His initial assignment typically is to pilot or co-pilot that aircraft.

EXPERIMENTAL TRAINING. The trainees who participated in the SFTS test received the same training, except that all instrument training was administered to them in the SFTS instead of in the TH-13T and the existing devices. Additionally, the UH-1 Contact Phase transition training received by this group was modified to take advantage of training received in the SFTS. Only the results related to the Instrument Phase training are described in this paper. The effects of SFTS training upon transition training requirements are not addressed.

TEST SUBJECTS. Sixteen test subjects participated in this study. They were selected, using a table of random numbers, from among the 34 active Army members of an Officer Rotary Wing Aviator Course who completed the primary phase of training (110 hours contact training in the TH-55) at the time the SFTS training was scheduled to begin and who volunteered to participate in the study. These trainees had no prior instrument flight training and had relatively little flight experience prior to entering the Army pilot training program. The maximum amount of prior flight experience was approximately 60 hours. The majority of the test subjects had received 35 to 40 hours pilot training in an ROTC private pilot training program prior to entering the Army.

INSTRUCTORS. Nine Army Officers, Warrant Officers, and Department of the Army Civilian Instructor Pilots (IPs) participated in this study. Eight of these were assigned two test subjects each, and the ninth was used as a spare in instances of the necessary absence of one of the other instructors. Initially, each instructor was either an Instrument Phase IP or a Contract Phase IP. Consequently, it was necessary to qualify the former in the UH-1 aircraft and to qualify the latter as instrument instructors. This was done by the U.S. Army Aviation School. The instrument training experience of these IPs thus varies considerably. It ranged from no prior instrument instructing experience to extensive IP experience and qualification as an Army instrument examiner.

Prior to the beginning of Phase III, each IP underwent training by the research staff in the manner in which the experimental training program was to be administered in the SFTS. Additionally, their performance was closely monitored throughout the training to encourage compliance with the training program design. These steps were necessary due to the fact that the experimental training program required numerous significant deviations from training practices to which these IPs were accustomed.

In addition to the IPs who conducted the experimental training, the SFTS instructor console was manned by non-rated personnel who assisted the instructors when they were conducting training from inside the cockpits. The chief functions performed by these device operators related to problem set-up and simulated ground station communication.

PROCEDURE. All instrument training was conducted in the SFTS on a proficiency basis. Necessary instrument flight related academic instruction was conducted under the supervision of each trainee's IP, using programed text books. Other training for the test subjects took place with comparable students who were not participating in this study. When the IP determined that his students met all proficiency requirements for award of an Army standard instrument rating, they were scheduled for a checkride.

RESULTS

Table 1 indicates the amount of training received by each trainee in the SFTS. At the end of that training, each trainee was administered an instrument checkride by a qualified Army instrument examiner who was not otherwise participating in this study. The time required for conduct of the checkride and the checkride grade are also indicated in table 1. It should be noted that two subjects did not pass the checkride the first time it was administered. In each case, they returned to their assigned IP for additional training and then were given a second checkride, which each then passed. Table 1 includes all training and checkride time required by these students. Army Aviation School policy dictates that the grade of 70 be assigned when any checkride is passed after having once been failed, regardless of the quality of the student's performance on the recheck.

The mean-time required for these students to pass the required instrument checkride in the SFTS was 42:50. Of this, 40:28 was devoted to training, and 2:22 to evaluating their performance during checkrides. This compares with the total training and evaluation time scheduled for all conventionally trained students of 60 hours in the TH-13T, plus 26 hours training time in the modified 1-CA-1 device.

Upon passing the instrument checkride in the SFTS, these experimental trainees were judged qualified, so far as proficiency was concerned, for award of a standard instrument rating. Present Army Regulations, however, require that such an award be made only upon the basis of performance during a checkride conducted in an aircraft. Consequently, the test could not be concluded until these trainees had been examined in the aircraft itself.

Each IP "transitioned" his assigned trainees from the SFTS to an instrument equipped UH-1H. This transition training was conducted under the hood or under actual instrument conditions, i.e., it did not include <u>any</u> contact flight training. (None of the trainees had prior experience flying the UH-1). Table 2 indicates the amount of time devoted to this aircraft familiarization activity. Transition training was restricted to familiarization with the aircraft under simulated or actual instrument conditions, since it was presumed that all necessary instrument training had been conducted in the SFTS.

TABLE 1. TRAINING AND CHECKRIDE TIME REQUIREMENTS AND CHECKRIDE GRADES OF TEST STUDENTS IN THE SFTS

Student Number	Training Time	Checkride Time	Total Time	Checkride Grade
1	33:15	2:15	35:30	89
2	35:00	2:00	37:00	82
3	35:00	2:00	37:00	84
4	37:30	2:00	39:30	73
5[a]	39:00	4:15	43:15	70
6	40:00	2:15	42:15	85
7	40:30	2:15	42:45	90
8	40:45	2:00	42:45	91
9	41:00	2:15	43:15	90
10	42:00	2:00	44:00	94
11	42:15	2:45	45:00	89
12	43:00	2:00	45:00	92
13[a]	43:45	3:30	47:15	70
14	44:00	2:15	46:15	80
15	45:00	2:00	47:00	82
16	45:35	2:00	47:35	86
Mean	40:28	2:22	42:50	84.2
S. D.	3:41	:38	3:47	7.6

[a]Students 5 and 13 did not pass the checkride in the SFTS the first time it was administered. Their performance was satisfactory on a subsequent recheck.

TABLE 2. AIRCRAFT FAMILIARIZATION AND CHECKRIDE TIME REQUIREMENTS AND CHECKRIDE GRADES OF TEST STUDENTS IN THE UH-1

Student Number	Training Time	Checkride Time	Total Time	Checkride Grade
1	3:00	2:00	5:00	87
2	3:00	2:45	5:45	88
3	6:15	2:00	8:15	88
4	4:45	2:00	6:45	84
5[a]	6:15	3:15	9:30	70
6	5:00	2:00	7:00	85
7	6:45	2:00	8:45	84
8	3:00	1:30	4:30	91
9	3:00	2:00	5:00	83
10	4:00	2:00	6:00	82
11	3:30	2:00	5:30	85
12	3:45	2:00	5:45	80
13	3:30	2:45	6:15	83
14	5:30	3:00	8:30	78
15	3:15	1:45	5:00	74
16	2:45	3:00	5:45	70
Mean	4:12	2:15	6:27	82.0
S. D.	1:21	:30	1:31	6.2

[a]Student 5 did not pass the checkride in the aircraft the first time it was administered. His performance was satisfactory on a subsequent recheck. See the text for comments about this student.

The aircraft time required for this transition training ranged from 2:45 to 6:45. The mean-time was 4:12. It should be noted that a portion of the range of training times was attributed to the IPs' judgment that some students needed more aircraft familiarization than did others. Some of the range, however, was a function of difficulties experienced in the scheduling of instrument equipped aircraft and qualified Army instrument examiners. The latter was a particular problem, since the timing of this test conflicted with the scheduling of these personnel for other duties. In fact, it was found necessary to have three of the aircraft checkrides administered by qualified instrument examiners assigned to the test as IPs instead of using exclusively independent evaluator personnel. In no case, however, did the assigned examiners check their own students.

The aircraft checkride times and grades also are indicated in table 2. It should be noted that one trainee failed to pass the inflight checkride on his first attempt. Unknown to test personnel at the time, this trainee had learned of the death of his mother the evening before the checkride and was awaiting a flight home when he took the checkride. It can be argued that he should not have been allowed to attempt a checkride under those circumstances. Upon returning from emergency leave, he was given one additional familiarization flight and then successfully completed the required checkride. This additional time is included in table 2.

The total calendar time required for the conduct of the experimental training in the SFTS and the familiarization flights and instrument checkrides in the aircraft for the experimental trainees was seven to eight weeks, excluding the one individual whose recheck was delayed by emergency leave. The conventional schedule programs twelve weeks for the Instrument Phase of Training.

DISCUSSION

The fact that SFTS training transfers to the aircraft should surprise no one. It is a high fidelity simulator of the training aircraft. Airline experience transitioning pilots to the 747 and other aircraft has shown that such equipment can provide effective training.

It has been said, however, that the airlines have been able to use simulators effectively because their pilot population is so sophisticated; that these commercial pilots already know all there is to know about flying, and it is just a matter of teaching them to operate a new item of equipment. Since the military undergraduate aviator is not so well qualified, his training must be conducted in the air, or so the reasoning would go.

The study reported here provides evidence that simulators <u>can</u> be used as effectively with undergraduate Army trainees as with highly experienced commercial pilots. In fact, so far as the Instrument Phase of Army undergraduate training is concerned, the training described here was significantly more effective than that conventionally conducted by the Army. The aircraft time was much less, approximately 6:30 hours altogether, for the test group versus 60 hours for the conventional trainees, and the total aircraft and simulator or training device time also was less, approximately 49 hours for the test group (including two checkrides) versus 86 programed hours for the conventional trainees. Also, calendar time was only 8 weeks, versus 12 weeks for the conventional program.

Certainly, the unique design-for-training features of the SFTS contributed to the transfer of training reported here. It should be obvious, however, that the manner in which the device was used contributed to these results perhaps as much as the equipment itself. Undoubtedly, had any existing synthetic training program been used, much of the potential effectiveness of the SFTS would have been lost. An appropriately designed training device can make transfer of training possible, but device design alone does not assure effective training.

The training was conducted on a proficiency basis. Thus, the amount of time required by each trainee to reach criterion performance varied considerably in both the SFTS and the aircraft. It might be assumed that the range of times reported in tables 1 and 2 reflect the times required to bring all students to essentially the same skill level. To an extent, such an assumption is supported by the evidence that more training time did not result in higher checkride grades. The product moment correlation coefficient between training time in the SFTS and SFTS checkride grade is .04, and the corresponding correlation between familiarization time in the aircraft and aircraft checkride grade is -.09.

It is the opinion of the writer, however, that a large part of the range in times should be attributed to differences in the instructing skills exhibited during the test by the IPs involved. Some of the IPs were more proficient in their administration of the training program developed for this test than were others. It is believed that more efficiency can be obtained in subsequent administration of SFTS training with a resulting reduction in the amount of training time required by the less proficient IPs and in the range of training time required.

Earlier in this paper, mention was made of principle features of the training program employed in this study. An additional feature should be added: throughout training, emphasis was placed upon training to stated behavioral objectives, and checks were made almost constantly to minimize inefficiencies resulting from extensive and unnecessary training beyond those behavioral objectives. The entire training program was criterion performance oriented. Conventional training activities, such as "attitude instrument flying" were included in the program only if they were found necessary to the attainment of the required behavioral objectives. In fact, the program is so unconventional that considerable doubt was expressed by experienced aviators concerning its workability. Their doubt has been resolved by the results obtained. The graduates of the SFTS test training program are indistinguishable from their conventionally trained fellow-students so far as measurable instrument flight proficiency is concerned. Only their log books show the difference.

It is clear that military pilot training organizations can make much more extensive use of aircraft simulators in their undergraduate pilot training programs. In fact, with properly designed equipment and training programs, much of the training now conducted in aircraft could be conducted more efficiently on the ground. With existing simulation and training technology, the conduct of 50% of present Army, Navy, and Air Force undergraduate pilot training on the ground might be a modest goal. Within a few years, I believe we will be able to raise that goal to somewhere in excess of 75%. But not if we sit back and say that the only way to learn to fly is to fly.

EFFECTS OF TRAINING SITUATION ANALYSIS ON TRAINER DESIGN

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One of the major branches of military training is maintenance training. In formal schools for aircraft maintenance training it is seldom practical to train personnel in flight line and hanger procedures on line aircraft. To aid in providing these skills, many training devices are employed. These devices each simulate portions of the real maintenance environment the student will encounter in his future work.

The form in which the maintenance task is simulated depends upon the particular training situation or the "use requirements" of the trainer in supporting the overall training course. The training situation therefore determines the general design of the device. Trainers may take many forms, from elaborate mock-ups of major portions of the airframe or its electronic systems, to a simple practice stand where a student can perform a maintenance task until the skills become automatic.

Ideally, flight-line and hangar maintenance training would take place in a real environment utilizing the aircraft, tools, test equipment, and procedures the maintenance man would encounter in actual practice. Unfortunately this is impractical in formal schools where numbers of students in many different specialities must be trained simultaneously and in a short training cycle. In the crowded confines of the aircraft, only one or two students at a time can work on any one operation. The maintenance tasks of the various specialities to be trained either conflict with each other or cannot be performed safely together. Additionally, many operations simply cannot be performed safely until the student has previously practiced and understood the principles. Since the aircraft is not an effective training tool for formal maintenance schools, other types of training devices are needed to expedite and enhance the training program.

A typical formal training program may be divided into two major parts; the lecture phase and the lab phase. The lecture phase provides first a general understanding of the principles involved, and then the how-to-do-it details. The lab phase of training follows much the same pattern of "principles" followed by "applications". The training situation, however, has now moved from the large group, motivated and force-fed by the instructor, to the individual or small group in a self-learning situation, where the principles and the how-to-do-it logic and skills are made their very own.

Training devices may be used effectively in both the lecture and the lab phases of the program. They can assist by adding a visual and tactile focus to the points of the lecture or by illustrating the principles presented. Training devices may be exceptionally useful in the lab phase of training in providing a place to practice how-to-do-it problem solving with tactile, visual, and audio reinforcement of the training.

Visual and audio aids of many kinds are available to assist the training program: films and tapes, projected or permanent graphics, programmed instruction devices, and plain old fashioned texts. In fact, the single most valuable aid is the aircraft maintenance manual itself. Each of these classes of aids can be of great value to the training program, and it would be very interesting to explore the effects of changing training situations on the design and use of these aids. However, none of these aids provide the student with tactile reinforcement of the lecture or with the opportunity to practice procedures until lecture theories become personal skills.

Student-operated training devices which simulate portions of the aircraft maintenance environment do provide this combination of theory reinforcement and tactile practice. It is our purpose here to explore the effects of changing training situations on the design of these devices for the Naval Air Maintenance Training Detachments (NAMTRADETS) and the Air Force Field Training Program.

The maintenance trainer of 20 years ago was aimed at the training-in-grade of already skilled personnel to maintain a basically familiar system, such as hydraulics, on a new model aircraft. Since the people were already skilled in their speciality, training cycles were short and aimed primarily at understanding the functions of the overall system rather than skills such as rigging or installing a hydraulic cylinder. As a result, maintenance trainers tended to emphasize overall system operation, relationships, or principles. These functions are best shown and taught graphically. The typical hydraulic system trainer of the period was an animated schematic on which system relationships could be demonstrated, isolated, or repeated at will, emphasizing the point of the lecture. Manual skills training and fault isolation practice using real hardware were not requirements for the maintenance trainer, and consequently, were seldom provided.

As the average time in service of the maintenance personnel decreased over the past 20 years, and the number of operating squadrons increased, the training load increased correspondingly. The operating squadrons were faced with increased training requirements to upgrade personnel, as well as transition training for improved models of aircraft. From this evolved the Air Force's Field Training Detachment (FTD), as well as an enhanced Naval Air Maintenance Training Group program.

The FTD's and NAMTRADETS, groups of full-time instructors equipped with maintenance trainers, are assigned to a base for a long period of time to assist operating squadrons with maintenance training. Instead of "transition-training" skilled personnel in grade, emphasis is placed on upgrading the skill level of the personnel. As a result, the design requirements for maintenance trainers changed to meet the increased emphasis on skills training. The animated schematic style trainer was typically replaced by an operating hardware mock-up of the system in the airplane, and graphic aids took over the task of illustrating system theory and function during the lecture phase of instruction. The maintenance trainer, therefore, became the primary training tool in the lab phase of instruction. The requirements for a typical maintenance trainer became: Provide familiarity with the equipment as it is installed in the aircraft; provide applied practice in maintenance operations, parts replacements, rigging, adjustment, and safety practices; and provide trouble shooting and fault isolation practice.

We have examined the general role of training devices in the maintenance training program today and the resulting requirements the trainers must fulfill. Let us now look in more detail at the process whereby the maintenance trainer is fitted to that role.

Before any requirement exists to design a trainer, the need for the trainer must be established. Aircraft system maintenance procedures are analyzed to define the skills needed by the maintenance personnel. Training requirements to provide these skills are defined and reviewed to determine which kinds of aids will best promote these skills. If a maintenance trainer is needed, the general nature of the trainer is determined. For example, would an operational mock-up, a static display, or an animated display best fulfill the requirements?

The next step is establishment of detail design requirements. If an operational trainer is to be provided, the requirements for operating the system in the classroom, isolated from the rest of the aircraft systems, must be determined. What input signals or output displays must be provided synthetically to allow a navigation system to function normally? What safety hazards exist around a radar system in a classroom? What security problems will an operating counter-measures trainer present?

Some general considerations in setting detail design requirements are:

- Accessibility to students.
- Maximizing the number of student training stations.
- Generating student enthusiasm.

- Good transfer of training to the aircraft environment.
- Transportability.
- A short engineering and delivery cycle.

When the detail design requirements have been fully developed, potential solutions to these requirements must be evaluated and the general configuration established. The proposed configuration is then submitted to the customer for approval.

With customer approval to this point, detail design or engineering can now begin. Designing is basically an iterative process. The general design is subdivided into functional components, and again requirements are established with alternative solutions sought and evaluated. Eventually a preferred design will be selected for each of the components. This process proceeds in ever greater detail until the design is complete.

Consider the effect a change in training requirements can have upon maintenance trainer design using two different training situations applied to two versions of RF-4 camera system trainers. The RF-4C camera trainer, shown in Figure 1, was designed to meet mobile training detachment requirements for "transition-training" personnel already experienced in their specialty. It consisted of an operational mock-up of the camera installations on two open panels. The viewfinder, cockpit equipment, and camera parameter control unit were mounted on an electronic workbench. The trainer featured transportability, easy access for system troubleshooting and maintenance practice, and numerous training stations. The trainer did not attempt to present realistically the conditions surrounding the performance of maintenance tasks in the aircraft. That form of "finger-dexterity" was not a requirement for the experienced personnel being trained.

The RF-4B camera trainer, shown in Figure 2, was designed for a permanent school to provide training for both skilled personnel transitioning to the new aircraft, and for personnel fresh from basic school who had yet to work on their first aircraft. In this case, transportability was not a prime requirement; thus the panels could be heavier and larger. Training in camera installation and removal, the use of camera hoisting equipment, camera door rigging, and system trouble-shooting was required. To provide these mechanical skills, as well as trouble shooting practice, a complete operational camera installation within the confines of a mock-up of the interior of the aircraft nose was mounted on one panel. The viewfinder and aft cockpit controls were mounted on an electronic work bench. Within the confines of the nose, all installations, clearances, and encumbrances provided realistic conditions in which to practice the desired skills under flight-line conditions. Since the trainer was designed for the Marines, some thought was given to adding rain and mud for utmost realism. After some consideration, this requirement was waived. This greater emphasis on "finger-dexterity" and realism of practice had a price. Easy transportability was sacrificed, the number of available student training stations was reduced, and ease of access for both lecturing and practice was lost.

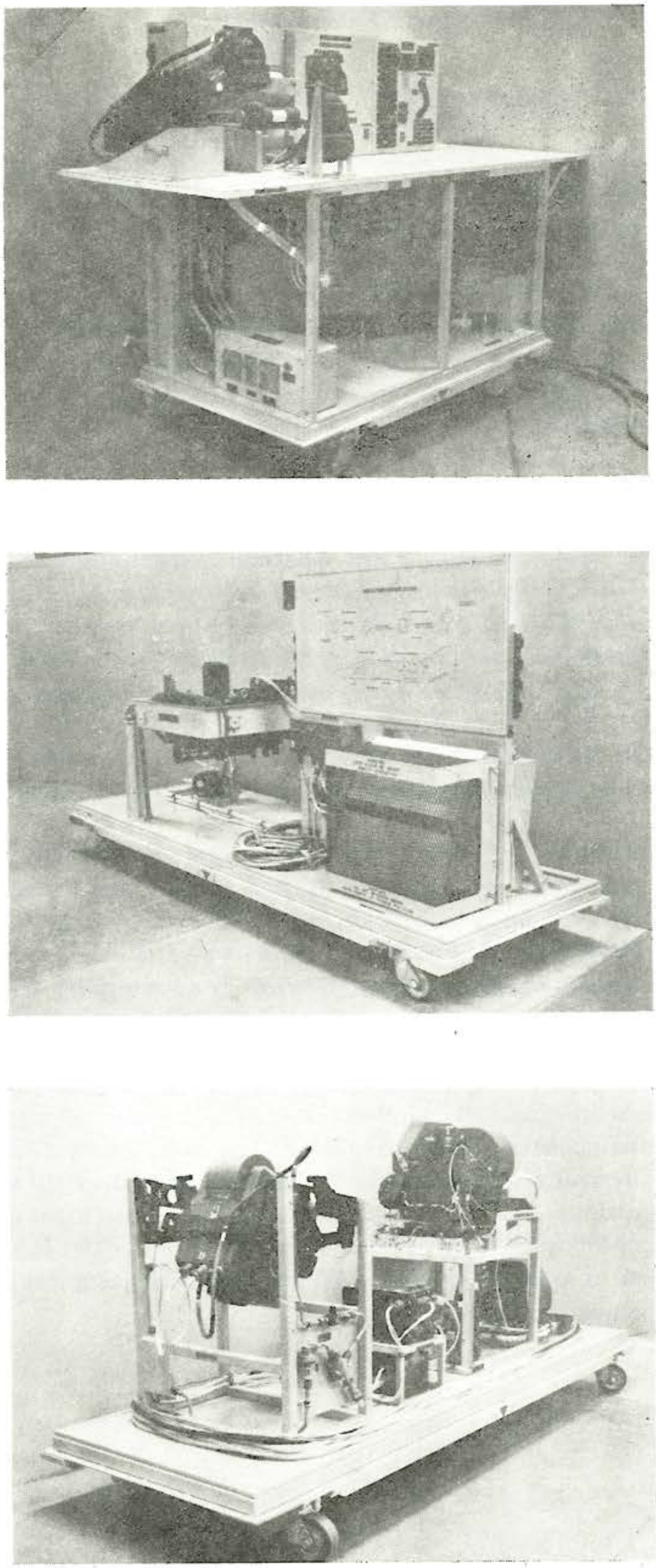

Figure 1. RF-4C Camera Trainer

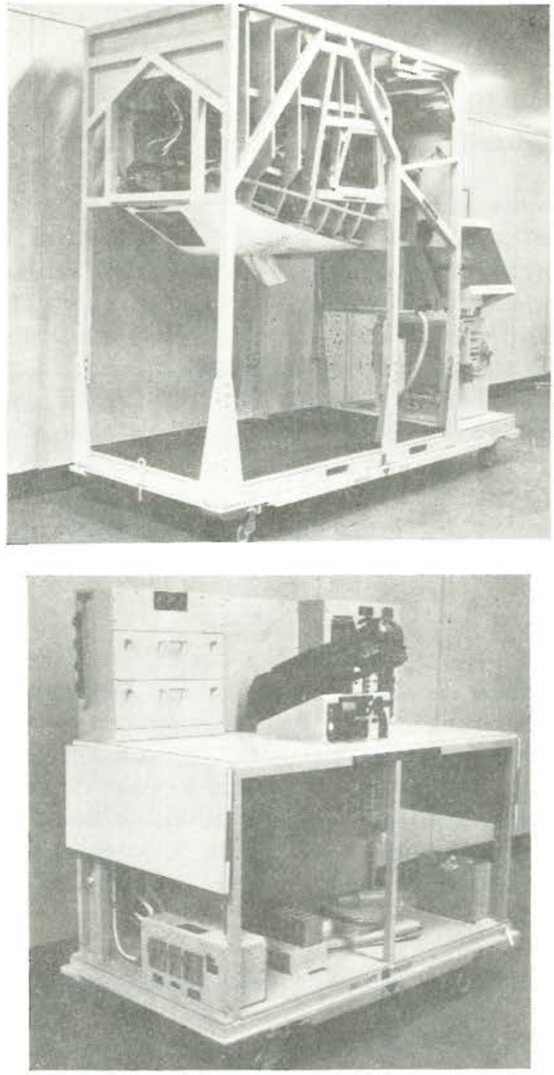

Figure 2. RF-4B Camera Trainer

In the above example, the final skills requirements of the maintenance people were the same for both schools. The RF-4B school expected to receive a greater percentage of students with little experience in maintenance of photo systems in aircraft and consequently additional requirements for applied skills training had to be satisfied. As a result, it became a design requirement to provide a greater degree of realism in simulating the aircraft maintenance environment in the RF-4B camera trainer. The changing training situation was reflected in the change in design described in the example.

In summary, economics of use require that formal schools use training devices to simulate the aircraft maintenance environment rather than use the aircraft itself. Individual trainers, of necessity, simulate only selected portions of that maintenance environment. Because of the economics of use, each trainer is a compromise satisfying only the most urgent training requirements which cannot be more economically fulfilled in some other way. Careful analysis of the projected training situation is required to establish and evaluate the training requirements to be met by the training device. Only with careful training situation analysis can the design of the trainer be guided to meet the needs of the training program and provide the customer with the best possible training capability for the money spent.

QUANTITATIVE TASK ANALYSIS AND THE PREDICTION OF TRAINING DEVICE EFFECTIVENESS

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Because of the enormous costs involved in the design and development of a complex training device, one can ill afford to adopt a "wait-and-see" attitude about the effectiveness of training which it provides. The primary problem confronting individuals responsible for military training, therefore, is how to plan for, design, and develop a training device from the very start, which will prove to be effective for a particular set of training objectives. But, given the requirements for training, how can one forecast or estimate how effective any specific design will be? For example, as designed will the device facilitate or inhibit ease of instructor operation (i.e., presentation of problem materials, monitoring and evaluation of student performance, provision of feedback)? Similarly, from the student point of view, will the design lead to rapid acquisition of skills and their positive transfer to the operational setting?

If answers to these types of questions could be given early in the design and development process, then a basis would exist for comparing and contrasting the "relative goodness" of alternative designs prior to actual development. By systematically evaluating alternative designs in terms of predicted training effectiveness, we might better be able to insure that the design finally adopted is better than other designs which may have been under consideration. This, after all, is the basic point. It would be desirable to have some early indication that the adopted design will provide superior training, relative to competing designs.

In the 25 years since World War II, few other training problems have received as much attention. The problem has come under repeated attack and has been approached from a number of different theoretical positions. Various methods have been conceived to help determine what should be trained and how training should be accomplished. Many of these approaches have shared the assumption that operational tasks possess certain critical characteristics which have specific implications for the design and utilization of training devices. It was hoped that this information, together with estimates of cost, would lead to training decisions which insured maximum returns for each training dollar invested. In spite of several efforts in this direction, however, the problem of prescribing the design of a training device, or of predicting its effectiveness, remains unsolved.

THE EARLY YEARS--INTUITING THE SOLUTION

Historically, gross inadequacies in the design of training devices were often eliminated on the basis of shrewd guesswork. In the earliest approaches, design decisions were made by subject-matter specialists, who drew on experience and common sense, to solve training design problems. As a result, they often were able to make fairly sound decisions about the design of training aids and equipment, student and instructor stations, and other aspects of the training situation which might facilitate the learning experience. However, these early practitioners were artisans. Because of their experience, they were able to translate certain types of information about the job to be performed into requirements for training. As is true of all artists, however, they differed in terms of their conceptualization of and their approach to the training problems which faced them. As a result, some were highly successful in making sound training decisions. Others were not. Furthermore, because of the informal and implicit nature of their methods, it was difficult to train others in their use. But the major disadvantage of this approach lay in the difficulty of evaluating the proposed training solution prior to its adoption. Predictions as to the effectiveness of training were scarcely better than opinion.

QUALITATIVE TASK ANALYSIS--A CERTAIN AMOUNT OF NAME CALLING

Because of the difficulties inherent in these individualistic methods, attention was focused upon the development of more formal and programmatic approaches. The results of these efforts were a number of job descriptive and task analytic procedures. Using these approaches, it became possible to describe jobs in terms of their major task components, and then to describe these components in terms of underlying task elements and activities. Description proceeded systematically through several levels. The earliest of these procedures (e.g., Miller, 1953; Miller & Van Cott, 1955) were designed to help specify those aspects of an operational task which should be considered as basic items of content in a training program. More recent efforts (e.g., Chenzoff & Folley, 1965), while retaining an interest in specifying the appropriate content of training, have also attempted to prescribe the manner in which training should be accomplished. Among the more advanced of these techniques is the Training Analysis Procedure (TAP) currently in use at the Naval Training Device Center. As described in the Fourth Annual Conference (Middleton, 1969), TAP is designed to aid in developing device requirements and translating these into functional characteristics of training hardware.

Other investigators have attempted to formalize training decisions by developing task classification systems having implications for training. These taxonomists shared the belief that basically different types of tasks did indeed exist. Given this premise, a logical step was to collect, sort, and catalogue tasks, casting them into their appropriate classes or families. For each identifiable class of tasks there might exist an unique or optimally effective set of training procedures. As a consequence of this thinking there have been several attempts to classify tasks and to specify for each class those training techniques which seem most appropriate (e.g., Willis & Peterson, 1961; Stolurow, 1964; Miller, 1969).

Many of the analytic and taxonomic methodologies developed to date have had their own particular problems. Most, however, have shared one weakness. They have become too dependent upon a process of name calling or labelling. A certain amount of name calling, of course, is inevitable, and in and of itself is harmless enough. But when a specific training decision may rest upon the label given a particular task element, and when we often can't agree on the label to apply (e.g., decision making, problem solving, inductive reasoning), then there is cause for concern. At this point the objectivity and reliability with which tasks can be described and analyzed are in doubt.

Such is the case with many of the classical task-analytic approaches. They have provided for the description of tasks in behavioral or functional terms (e.g., the behavioral taxonomy of Berliner, Angell, & Shearer, 1964; the functional descriptors employed by Gagne, 1962; and by Miller, 1966). These terms have been found difficult to apply unambiguously. This difficulty, coupled with the fact that the terms in use permit only qualitative distinctions to be drawn among different tasks, limits the utility of these approaches. While they may help to determine the basic content of training, and although they may even provide general guidelines about how training should be conducted, these approaches will not aid in the prediction of training effectiveness.

QUANTITATIVE TASK ANALYSIS--PIGEON-HOLDING BY THE NUMBERS

In order to augment these conventional task-analytic procedures, therefore, the Naval Training Device Center has been seeking alternative ways of using information about the features of a training device and about the characteristics of the tasks performed within that device. Desired is a more reliable and objective method of task description which might be used to forecast training effectiveness. Underlying this effort there have been two issues of primary importance. First, would measures of training effectiveness (i.e., rate of skill acquisition, level of transfer) vary in some predictable manner as features of a training device were manipulated? Unless there was a relationship between these two sets of variables, prediction of effectiveness would not be feasible. Second, and even more basically, would it be possible to describe the critical features of a device reliably and along a number of quantitative dimensions? Unless such description were possible, there would be no way of investigating the relationship of interest.

To resolve these issues a research program was initiated by the Naval Training Device Center and the American Institutes for Research (AIR) which had three objectives. These involved: (a) Exploring ways of reliably describing features of trainee or instructor stations in quantitative terms; (b) determining whether the quantitative descriptors could be used to describe fairly complex devices; and (c) developing statistical methods for relating the quantitative descriptors to variations in device effectiveness.

In pursuit of these objectives, a variety of computer-driven and tape-based sonar training devices were examined, in order to identify features, which could be quantified. As a result of these efforts, a number of quantitative task-descriptive indices were assembled. These indices, developed by AIR, represented critical dimensions of the stimulus, response, and procedural aspects of trainee and instructor stations. Critical dimensions were those which, if manipulated, would be expected to affect level of (instructor) proficiency, rate of skill acquisition, or degree of transfer. Included among the indices were a variety of rating scales relating to such dimensions as work load, precision of responses, and response rate. Other indices were based on metrics such as the Display Evaluation Index (DEI) developed by Siegel and his co-workers (Siegel, Miehle, & Federman, 1963) and the several panel layout metrics developed by Fowler and his associates (Fowler, Williams, Fowler, & Young, 1968). The DEI is basically a measure of the effectiveness with which information flows from displays, via the operator, to corresponding controls. The panel-layout indices represent the extent to which general human-engineering principles have been applied to the design of hardware.

Application of the indices to four trainee tasks; (i.e., set-up, detection, localization, and classification) as represented in a variety of different sonar training devices, was attempted. This exercise demonstrated that most if not all of the indices could be used reliably to scale the extent and manner in which the trainee tasks differ across devices. By extension, therefore, the indices can be used to describe reliably and quantitatively how competing designs of the same device differ.

Can such quantitative information be related to measures of training effectiveness? In the final analysis, there is no way of specifying a priori which indices will bear a relationship to measures of performance, learning, or transfer. In order to explore the relationship between variations in design parameters and training effectiveness criteria, additional research is required.

Such research has been undertaken by AIR for NAVTRADEVCEN and is currently in progress. Training-effectiveness data are being collected both in the field and in the laboratory to provide criteria for regression analysis. The laboratory data are being obtained with the aid of a synthetic "trainer" which is an abstraction of the many sonar devices examined earlier in our research for NAVTRADEVCEN. The field data are being obtained through questionnaires, given to instructors and to trainee personnel. These questionnaires are designed to elicit estimates of the effectiveness of specific sonar trainers under standardized conditions. Use of the questionnaire, as opposed to more explicit performance evaluation, is being employed because of the well-known difficulties of accessing field equipment directly. Based on these field and laboratory data, regression equations will be developed. Such equations, if successfully validated, would permit the effectiveness of a given design to be predicted from knowledge of index values descriptive of that design. That is, we could then "pigeon-hole" by the numbers.

The trend away from purely qualitative task analysis procedures toward more quantitative techniques will result in improved training solutions. Such techniques offer promise in assuring the effectiveness of a training device earlier in the design process. Until these techniques are formally developed, predictions of trainee or instructor proficiency on particular trainer configurations will continue to be as much art as science.

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SESSION II

Tuesday, 15 February 1972

Chairman: Mr. George Derderian
Head, Physical Sciences Laboratory
Naval Training Device Center

A MODIFIED MODEL FOR VISUAL DETECTION*

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AND
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The requirement to predict the human ability to visually search and detect has occurred in a wide variety of problem areas. At Cornell Aeronautical Laboratory, Inc. (CAL) specific areas involved both ground-to-air and air-to-air search for aircraft against a sky background, and the search for small targets presented in simulator displays.

Models to predict human visual performance have been available for some time. The purpose of our paper is twofold: (1) To present a modified version of a widely known visual detection model and; (2) to compare the predictive capability of the modified version with both the original model and results of field tests involving ground-to-air search for aircraft.

THE MODEL

The first comprehensive work on visual search of a homogeneous background was done by Craik in the early 1940's. The results of his study, along with those of other studies to account for performance degradation due to atmospheric haze and to describe the detection process in a probabilistic fashion, have been organized by Koopman (1946) into a very workable and convenient model. Although the model is widely known, it is necessary to summarize its main features for this discussion:

1. In free search the eye does not scan continuously, but jumps from point to point. The eye remains fixed at each point for approximately 1/3 second for search in a homogeneous or unstructured background although longer fixation or "glimpse" times can be anticipated for search in complex backgrounds. The point in the visual field conjugate to the center of the fovea (retinal region of maximum acuity) is known as the point of fixation.
2. Target contrast (C) is defined as the average luminance difference between the target and its background, divided by the background luminance. The threshold contrast of a target (C_t) is the contrast at which the detection probability for a single glimpse assumes some nominal value. Koopman has employed a probability value of 0.57, and has expressed the threshold contrast for a single glimpse by:

$$C_t = \begin{cases} k_1 \theta^{k_2} + \dfrac{k_3 \theta^{k_4}}{\alpha_2} & (\theta \geq \theta_f) \\ k_1 \theta_f^{k_2} + \dfrac{k_3 \theta_f^{k_4}}{\alpha^2} & (\theta < \theta_f) \end{cases} \quad (1)$$

*This work was sponsored by the United States Air Force under contract number F33615-68-C-1319.

where: θ = angle subtended at the eye (in degrees) between the point of fixation and the target ($\theta \doteq 90°$)

θ_f = half-angle of fovea ($\theta_f = 0.8°$)

α = average angular diameter (minutes of arc) of the target subtended at the eye

$k_1 = 0.0175$ $\quad k_3 = 0.19$

$k_2 = 0.5$ $\quad k_4 = 1.0$

3. The probability of detection (g) during a single glimpse depends only on the ratio of target contrast to the threshold contrast of the eye (C/C_t) and is given in figure 1.

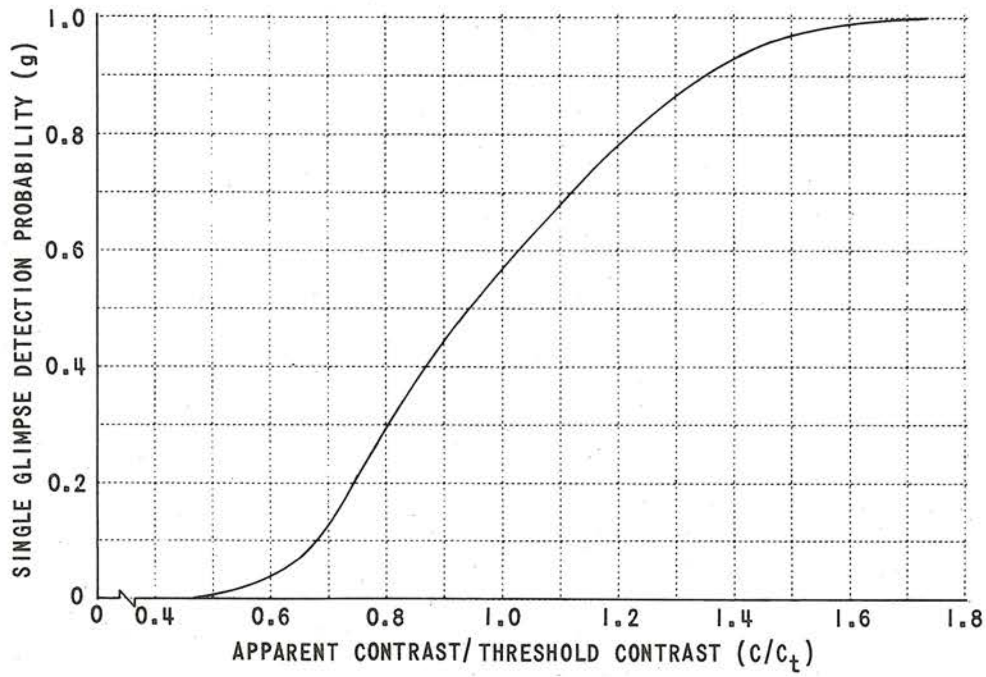


Figure 1. Glimpse Probability of Detection "g" vs Apparent Contrast/Threshold Contrast, C/C_t

4. Contrast is degraded by the atmosphere. Due to scattering by haze, the apparent target contrast (contrast seen by the observer) is reduced according to path length and haze concentration. The haze concentration is determined from the meteorological range, a mathematically precise measure designed to correlate with the general ability of the human to see through the atmosphere. The relation between the the contrast apparent to an observer (C) and the inherent contrast (C_o) was given by Middleton (1968) for horizontal view paths:

$$C = C_o e^{-\sigma R} = C_o e^{-\frac{(\ln 50)R}{V}} \qquad (2)$$

where: σ = optical attenuation coefficient of atmosphere (meters^{-1})

R = separation distance between observer and target (meters)

V = meteorological range (meters)

An account of atmospheric degradation for slant paths requires a much more complex mathematical description. Since such a generalization is peripheral to the theme of our paper, we shall confine our discussion to view paths that are essentially horizontal.

5. The search procedure consists of "continuously glimpsing" (one glimpse after another) at spatially random points within the designated search field. The probability of detecting the target during a single glimpse (instantaneous probability) is given by simply averaging "g" over the search field:

$$\bar{g} = \frac{2\pi}{M^2\Omega} \int_0^{\theta_0} g(\theta) \sin\theta \, d\theta \qquad (3)$$

where: $\bar{g}$ = average detection probability for single glimpse

Ω = solid angle of search field

θ_0 = one-half the apparent field of view of optics (e.g. 90° unaided eye, 28° binoculars)

M = linear magnification of optics

It should be noted that in addition to the search field Ω , an account of masking by the field stop is also included.

MODEL MODIFICATION

The model described above has undergone two modifications during its use at CAL. First, the mathematical expression relating threshold contrast, target size, and position in the visual field has been adjusted to agree with specific data subsequently published in the literature. The motivation for this was our feeling for some time that the detection ranges predicted by the model were on the high side.

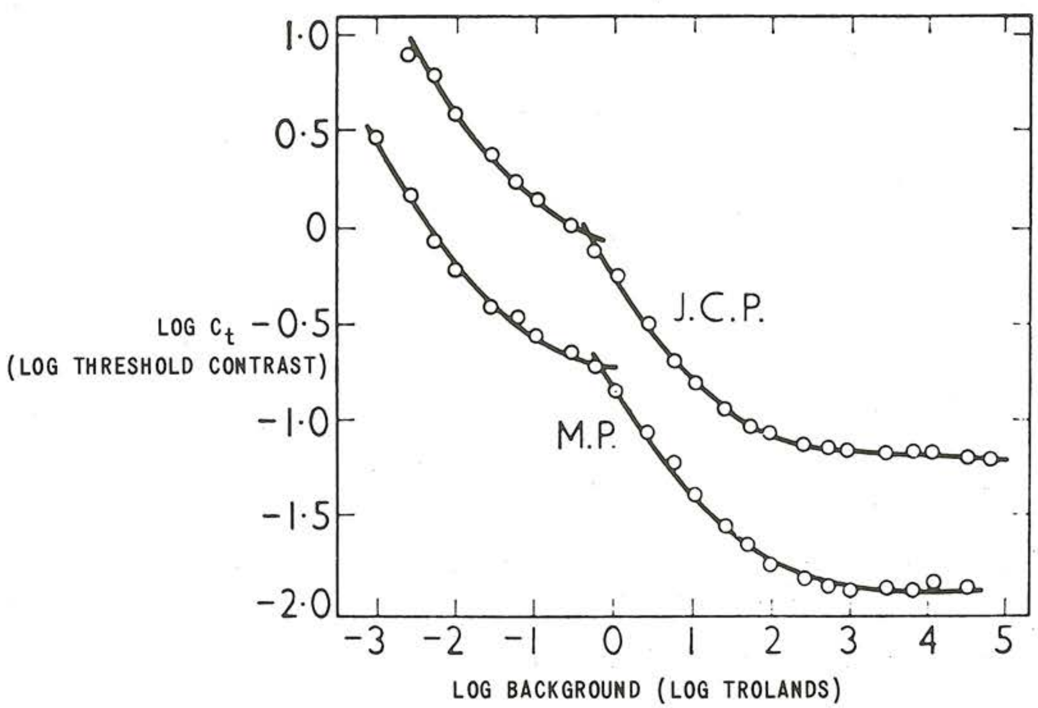
Second, the actual distributions of the peripheral angle (angle between the aircraft and the visual fixation point subtended at the observer) have been generated for various postulated geometric configurations involving the search field, target location and random search distribution. These distributions are used as a base for computing the average glimpse detection probability $\bar{g}$. (Although only specific distributions were employed in our study, any configuration can be handled by generation of its corresponding distribution.) Prior to the use of these distributions, the integration involved in determining $\bar{g}$ assumed the significant region of the visual field was completely contained within the search field, an approximation that allowed the simple integration procedure indicated by Equation (3).

*For our application, Weber's Law states that the brightness difference at threshold is proportional to background brightness.

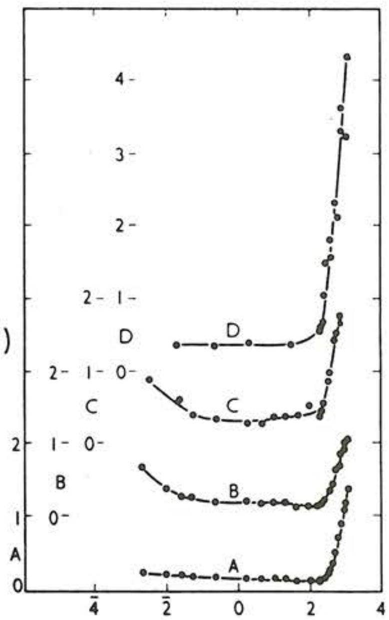
MODEL ADJUSTMENT TO NEW DATA

The threshold contrast expression (Equation (1)) was adjusted to fit threshold data published by Sloan (1961). Sloan has measured, for monocular viewing, "just perceptable differences" of small stimuli against a uniform background. She presented oval stimuli of uniform luminance for durations of approximately one second. The range in angular subtense (average diameter) at the eye was from 3 min of arc to 100 min. The "oval" nature of the stimuli resulted from optical distortion in the apparatus, not design, but the ratio of largest to smallest dimension was always less than 2:1. The thresholds were taken at a background luminance of 3.16 mL (10 nit) and include the dependence on position in the visual field. Only stimuli brighter than the background were used.

Initially there were two points of concern regarding the use of the Sloan data with the background level of 10 nit since this level is two to three orders of magnitude smaller than the daytime sky. The first relates to the validity of Weber's Law* which provides that background and stimulus brightness affect target detection only through contrast. Pirenne (1962) clearly illustrates (figure 2a) the validity of the law for retinal illumination levels above 1000 trolands. However, Sloan's background of 10 nit results (via adaptation) in an eye pupil diameter of 4 mm (LeGrand - 1957) thus yielding a retinal illumination of only 125 trolands. It is seen from figure 2a that the departure from Weber's Law is very small at this level and one can anticipate that the error arising from the departure may be negligible compared to the correction obtained by employing the Sloan data.



a. Threshold Dependence on Background for Two Observers (J.C.P., M.P.) (The Points for M.P. have been lowered 0.5 Log Units)



b. Threshold Dependence of Rods Only on Background For 4 Observers (A,B,C,D)

Figure 2. Threshold Dependence on Background Luminance (After Pirenne - 1962) (Reproduced through permission of Copyright Holder, Academic Press, 1962)

The second point of concern was regarding the role of the rods in the detection process. The spectral distribution of Sloan's background and stimulus was essentially that of Illuminent A (Tungsten) and therefore the illuminance of 125 trolands converts to 70 scotopic trolands when adjusting for the spectral response between cones and rods. It is seen (figure 2b) that this falls in the upper part of a sensitivity range for which Weber's Law is valid for the rods. Also it is a range of maximum contrast sensitivity (minimum contrast threshold) of the rods which does not correspond at all to sky background at which rod saturation is achieved. Although this difference exists, it is not believed to be important since, as indicated in figure (2a), the transition from cones to rods as the determinant of threshold occurs slightly below 1 troland and Sloan's value of 125 trolands provides a safety factor of two orders of magnitude.

There are three points that should be made regarding Equation (1). The first relates to the rotational symmetry of C_t about the fixation point. Equation (1) provides that C_t does not depend on both angular coordinates of the stimulus in the visual field, but only on the difference angle between the stimulus and the fixation point. Although Sloan's data indicate an asymmetry (primarily in the horizontal meridian) it is not large, and is somewhat averaged out for an observer using both eyes. Second, no statistical definition of threshold contrast was used by Sloan, so we assume her data to lie in the region of 50% detection probability, and therefore they were arbitrarily equated to C_t of Equation (1). Should the assumption be proved invalid the abscissa of the single glimpse probability curve (Figure (1)) can be scaled accordingly. The third point relates to the dependence of threshold contrast on stimulus size. Sloan states that the data are usually fitted by an equation of the form:

$$C_t = \beta_2 (\alpha^2)^{-\beta_1} \tag{4}$$

where β_1 and β_2 depend only on position in the visual field. Of the two possibilities for fitting a model to Sloan's data (Equations 1 or 4) Equation (1) was used since it is more reasonable asymptotically for both small and large α. The difficulty with Equation (4) can be understood by considering the asymptotic constraints on β_1. As α becomes small, point stimuli are approached and C_t must vary as α^{-2} thereby requiring $\beta_1 = 1$. For large α, we expect C_t to be relatively insensitive to α thereby indicating a β_1 close to zero. Since β_1 does not depend on α, Equation (4) cannot hold over such a large α range, and we shall not consider it further.

The data selected for fitting Equation (1) is shown in figure (3a). This data was fitted by varying $k_1 \ldots k_4$ of Equation (1) to minimize a square error (ϵ). It was decided to minimize in log space without a weighting function. That is:

$$\epsilon = \sum_{\substack{\text{data}\\ \text{points}\\ (\theta \neq 0)}} \left(\eta_{d.p.} - \eta_{Eq.(1)}\right)^2 \tag{5}$$

where η is the log of the threshold brightness difference in units of $\log \mu L$. The value of $\eta_{Eq.(1)}$ is related to C_t of Equation (1) by:

$$\eta = \log C_t + 3.5 \tag{6}$$

The term "3.5" in Equation (6) is simply the log of Sloans background luminance in $\log \mu L$.

The square error (ϵ) of Equation (5) was minimized using a direct search procedure which resulted in the following new values:

$$k_1 = 0.0265 \qquad k_3 = 0.44$$
$$k_2 = 0.24 \qquad k_4 = 1.6 \tag{7}$$

It is the replacement of these k values for those indicated in Equation (1) that comprises the major modification of the visual detection model. Threshold curves (in the ordinate η) are shown in figures (3b) and (3c) for the former and the present values of k respectively. The new values provide a substantially better fit to the data, with the most significant change being a large increase in the threshold for small stimuli in the peripheral region.

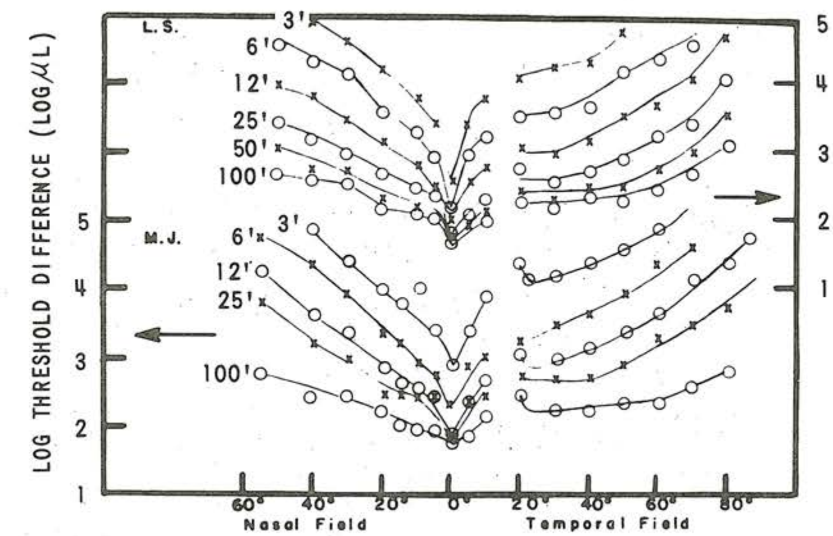
PERIPHERAL ANGLE DISTRIBUTIONS

The determination of the single glimpse detection probability (g in figure (1)) requires specification of the threshold contrast C_t which in turn depends on the peripheral angle (θ) in Equation (1). That is, formal elimination of C_t between Equation (1) and figure (1) allows us to write:

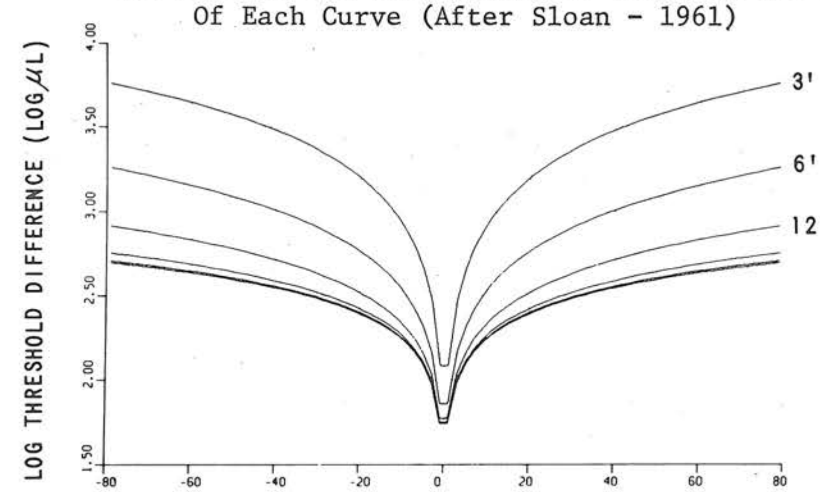
$$g = g(\theta) \tag{8}$$

where the arguments C and α have been dropped since our interest here is only with the angle θ. The peripheral angle θ is the angular difference (at any instant) between the stimulus (target) and the visual fixation point subtended at the observers eye. Since it is customary to treat the target and fixation positions as random variables, the peripheral angle is also a random variable. Thus in order to establish an explicit value of detection probability at any "instant" (single glimpse), it is necessary to specify the target and fixation positions as probability distributions, and compute an expected value ($\bar{g}$) over the search field.

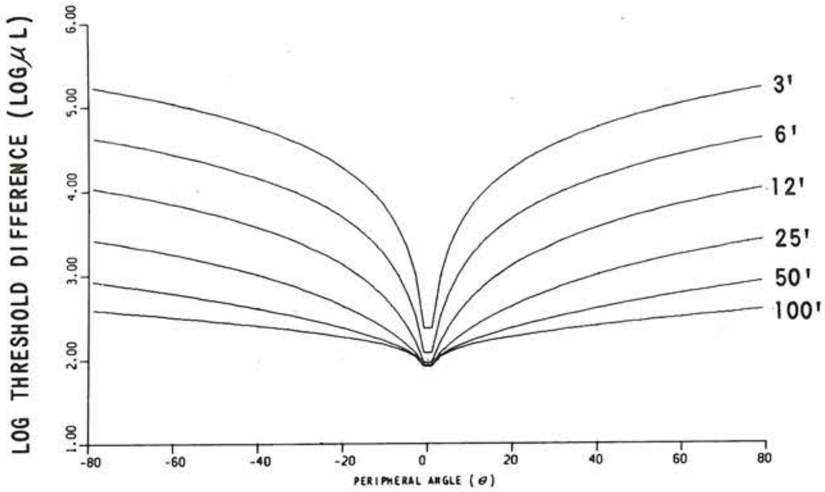
The original model assumes a uniform distribution of target position within the search field. It was further assumed that the region of the visual field surrounding the fixation which is important to detectability in the practical case is small, and therefore the border of the search field can be ignored when carrying out the averaging integral. These two assumptions allow $\bar{g}$ to be written according to Equation (3).



a. Threshold Gradients in the Horizontal Meridian The Size of the Test Object is Shown at the left Of Each Curve (After Sloan - 1961)



b. Threshold Gradients Predicted by Original Model



c. Threshold Gradients Predicted by Modified Model

Figure 3. Comparison of Data and Model Threshold Gradients

With regard to the two assumptions underlying Equation (3), the latter, involving negligible interaction between the visual field and search field border, is easily dropped. With complete generality we can write:

$$\bar{g} = \int_0^{\pi/2} P_e(\theta)\, g(\theta)\, d\theta \tag{9}$$

Where $P_e(\theta)$ is the actual probability density of the peripheral angle θ and includes all the information defining the search field, optical magnification and the distributions of target and fixation within the search field. The establishment of distributions (P_e) for the search configurations of interest and the computation of $\bar{g}$ through Equation (9) are, in essence, incorporated in the present model as a replacement for Equation (3).

The use of the distribution $P_e(\theta)$ is somewhat clumsy due to the dependence on optical magnification. That is, a separate distribution would have to be generated for each magnification value desired in order to compute $\bar{g}$. It was found to be convenient to write Equation (9) in terms of the angle (θ') separating the target and corresponding fixation point as it occurs in the actual search field Ω_o. Clearly, the relation between θ and θ' is:

$$\theta = M\theta' \tag{10}$$

Where: θ = peripheral angle within visual field (at eye)

θ' = peripheral angle in real world.

In terms of θ', Equation (9) can be written*:

$$\bar{g} = \int_0^{\pi} P(\theta')\, g(M\theta')\, d\theta' \tag{11}$$

*The Upper limit of π in Equation (11) is symbolic. It simply implies the integration is carried out until either P or g becomes zero. It was used to provide validity should the magnification ever be less than unity.

Where $P(\theta')$ is the probability density of the angle θ', and is independent of magnification.

Initially it was attempted to generate $P(\theta')$ distributions assuming the target and fixation distribution were distributed uniformly within the search field and a corresponding equation for the distribution is derived in the appendix. This approach was abandoned since it was too time consuming on the computer. It was decided instead to compute $P(\theta')$ for specific target positions, and the equation for this distribution is also given in the appendix.

Specific distributions were generated again assuming a uniform fixation density within various search fields of interest, and examples of the distribution are shown in figure (4). The fine structure along the tops of these distributions is coherent noise in the form of a moiré pattern resulting from overlapping of the search field border and the discretely sampled coordinate system used in the actual computer calculation of the distributions. The fluctuations are small and can be ignored.

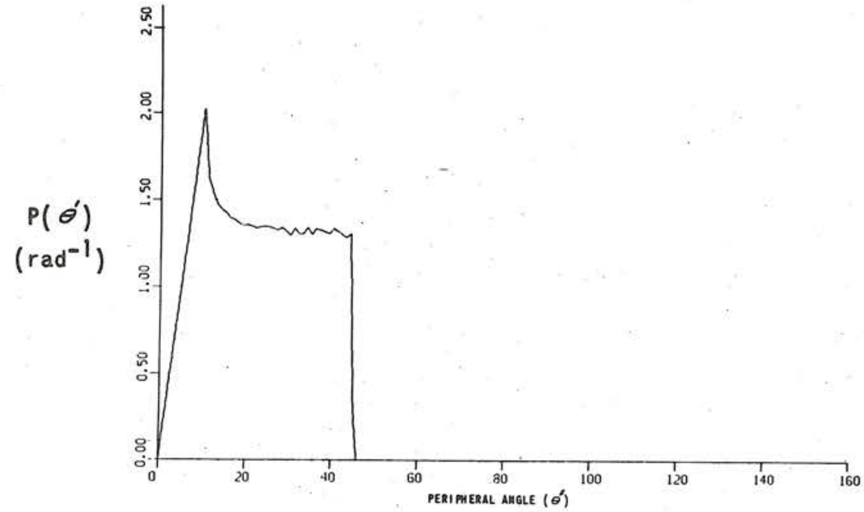
The distributions were punched on cards and are available as data arrays within the computer verison of the present model. Computer test runs indicate only slight differences between the detection probability values resulting from the former and present expressions for $\bar{g}$ (Equations (3) and (11) for the search geometries of interest in the present study. However, other search configurations may result in large differences and for that reason, Equation (11) should be employed.

COMPARISONS OF ORIGINAL MODEL, MODIFIED MODEL, AND FIELD TEST RESULTS

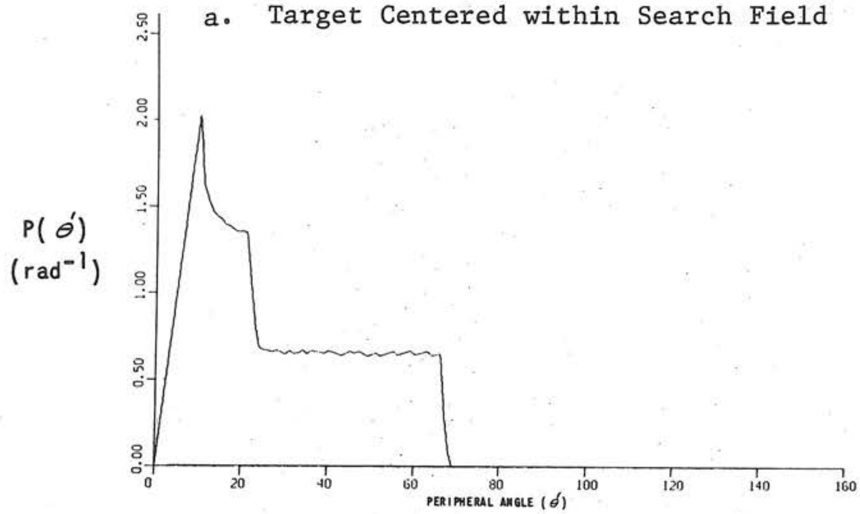
Having made the two model modifications just discussed, the next step was to determine the present model's predictive capability by comparison of the original and modified detection models with experimental results reported in the literature. An attempt at such comparisons quickly revealed the difficulties that are encountered when trying to verify a model with experimental data obtained from tests not designed specifically for verification of the particular model. Usually the experimental data are incomplete in their specification of one or more of the conditions of the experiment which are necessary for model inputs, i.e., contrast, meteorological range, glimpse time, target area, and search field size.

One notable exception is the experimental work reported by E.K. Seyb (1966) in which results are given for detections by the unaided eye from field tests conducted in Germany. The results are plotted in a meteorological visibility-detection range coordinate system, with cumulative probability of detection as a parameter, for the typical parameter values given in table 1. Seyb also mentions that, "as far as meteorological visibility was concerned, the test results of the German field tests were only available in intervals of 2 km." The experimental data were converted for purposes of the present study, to cumulative probability of detection versus range for constant values of meteorological visibility. This form of the data is compared with results obtained from runs of both the original and modified models using as inputs the values given in table 1.

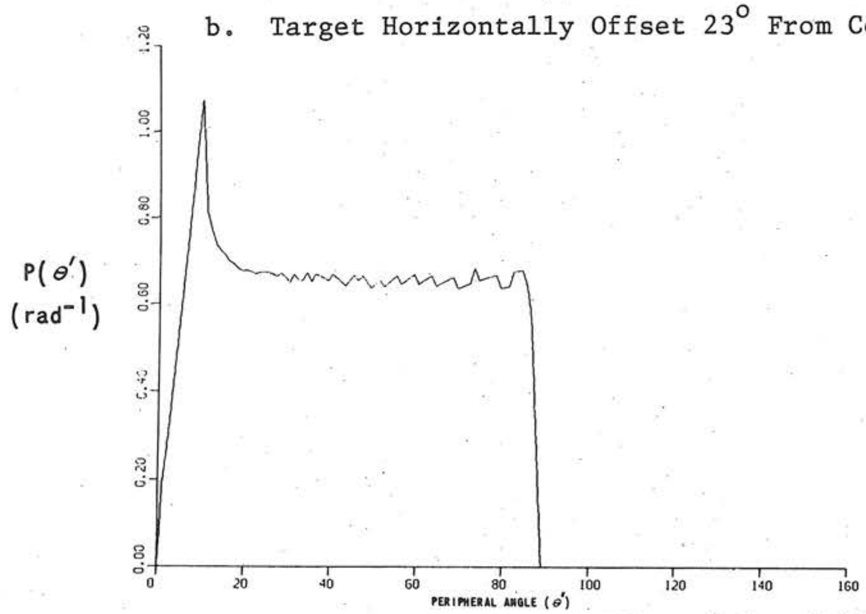
It should be noted that the only reference to aircraft size is through the visible area of 5.5 meters^2. The aircraft was not specified by Seyb, but since the altitude is low, and radial flight paths were employed, the visible area was not varied during the computer runs.



a. Target Centered within Search Field



b. Target Horizontally Offset 23° From Center



c. Target Horizontally Offset to Edge of Search Field

Figure 4. Peripheral Angle Distributions for a Search Field 90° in Azimuth and to 20° Above the Horizon

TABLE 1. FIELD TEST CONDITIONS
(AFTER SEYB - 1966)

Parameters	Mean Values
Velocity	60 m/s
Altitude	0.1 km
Offset	0.0 km
Inherent contrast, C_o	0.93
Glimpse Time	1.5 sec
Visible area	5.5 m^2
Search Field Size	30° Az x 5° El
Meteorological Range	5, 7, 17, 21 km

We should also mention that it was necessary to assume a target position within the 30° x 5° search field in order to generate a peripheral angle distribution for the modified version of the model. A location of 5° Az from the search field center, and 2° El above the horizon was employed.

Figures 5a and 5b compare experimental results with model prediction for meteorological visibilities of 21 and 17 km, respectively. Experimental data points are represented by circles. The theoretical predictions include those made using the original model as well as those obtained using the modified model. It is readily seen that for a given probability of detection, the original model results consistently predict greater ranges of detection than the modified model. Additionally, the modified model predicts the experimental data fairly well. Results for meteorological visibilities of 7 and 5 km are shown in figures 6a and 6b, respectively. Here, again it may be seen that the cumulative curves obtained with the original model lie at greater ranges than those obtained for the modified model. The modified model results, again, lie closer to the experimental data. The larger discrepancy between model and experimental results for the lower meteorological visibilities may be partially a result of the interval of presentation of the data; i.e., test results were available only in intervals of 2 km.

SUMMARY

The primary result of this study has been the modification of an existing visual detection model to provide better agreement with known performance data. Comparisons with field data have shown the modified version to be preferable to the original, since the original predicts a highly optimistic detection performance. Based on these comparisons, we recommend the use of the modified version in problem areas whose conditions are consistent with the model features described above.

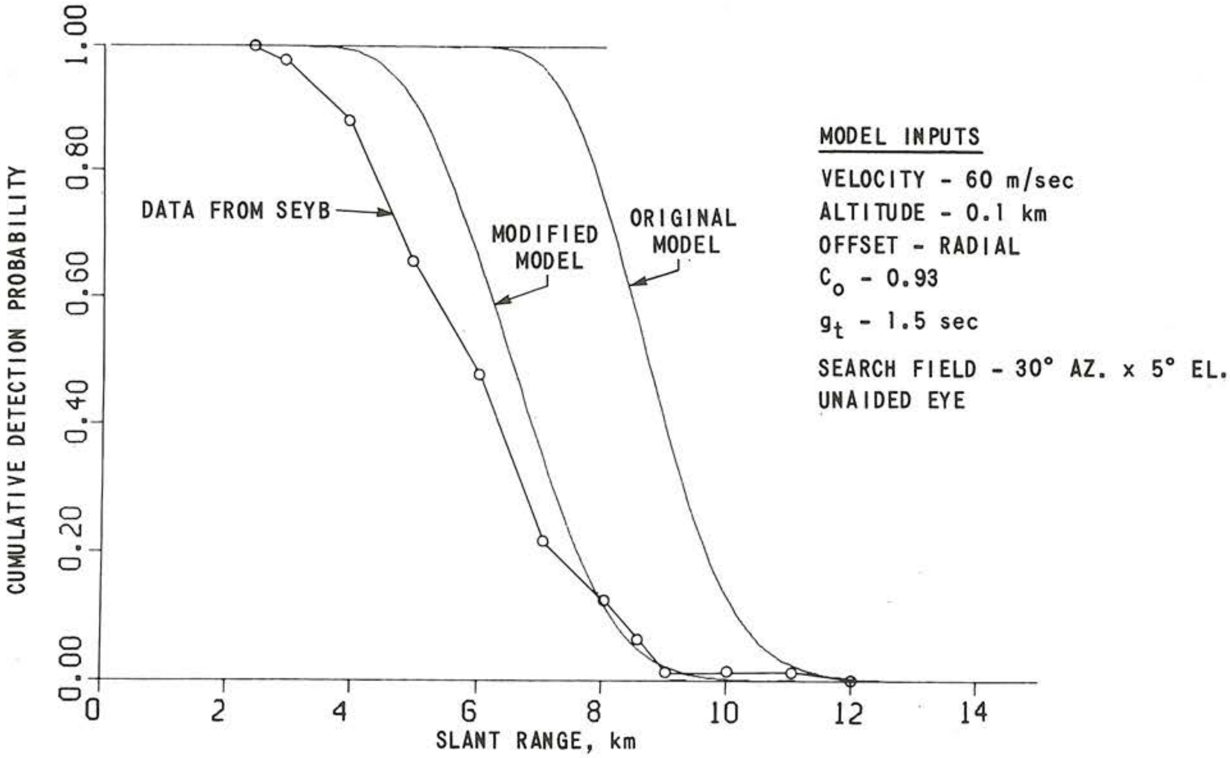


Figure 5a. Cumulative Detection Probability-Comparison of Model Results and Field Data with 21 KM Visibility

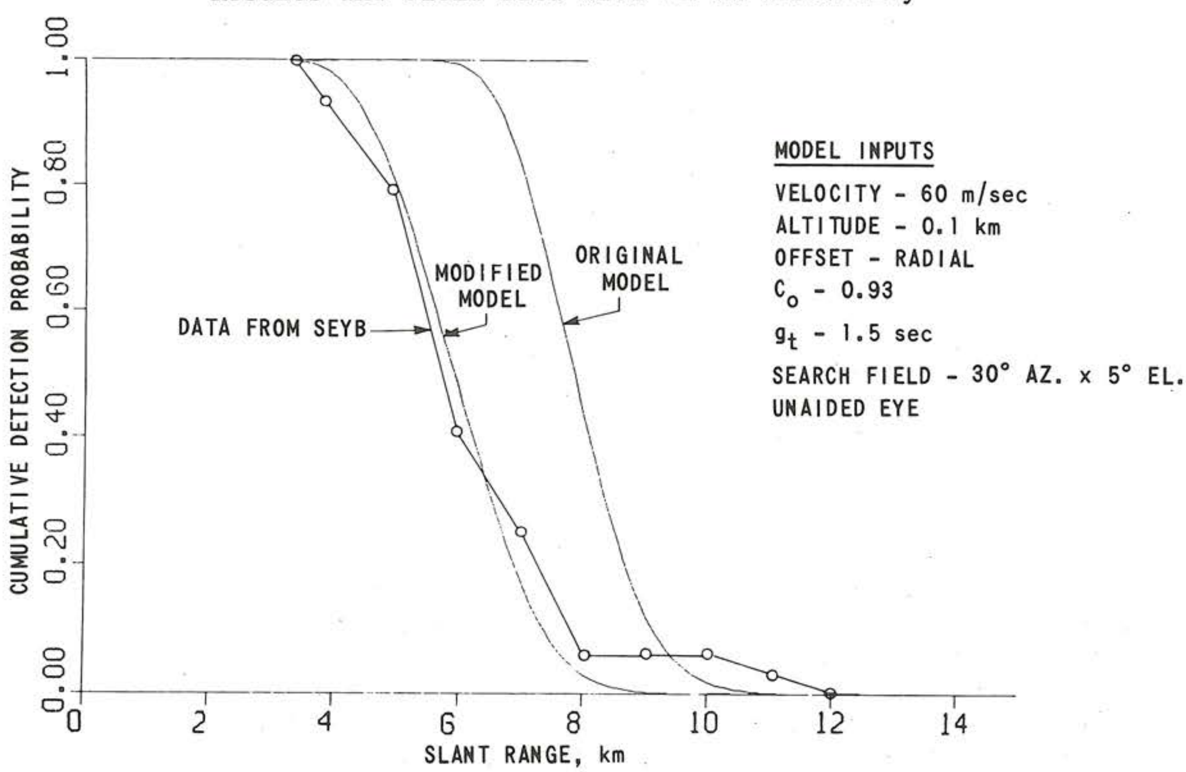


Figure 5b. Cumulative Detection Probability-Comparison of Model Results and Field Data with 17 KM Visibility

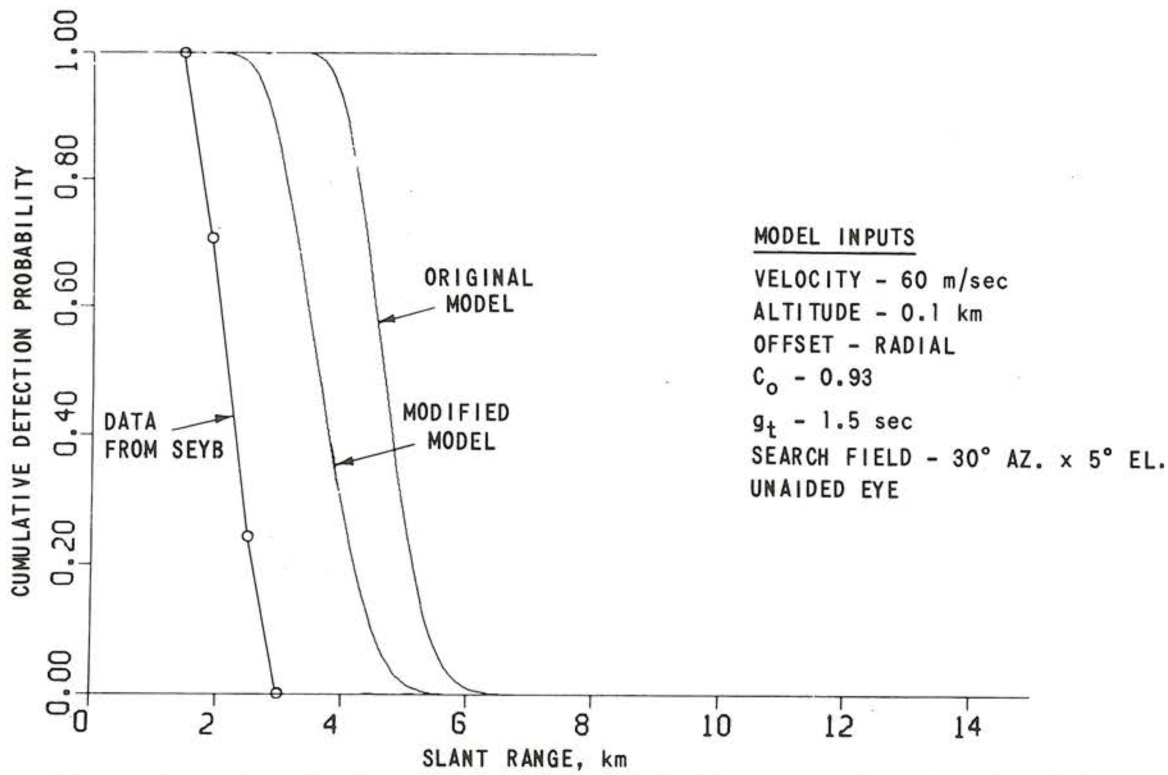


Figure 6a. Cumulative Detection Probability-Comparisons of Model Results and Field Data with 7 KM Visibility

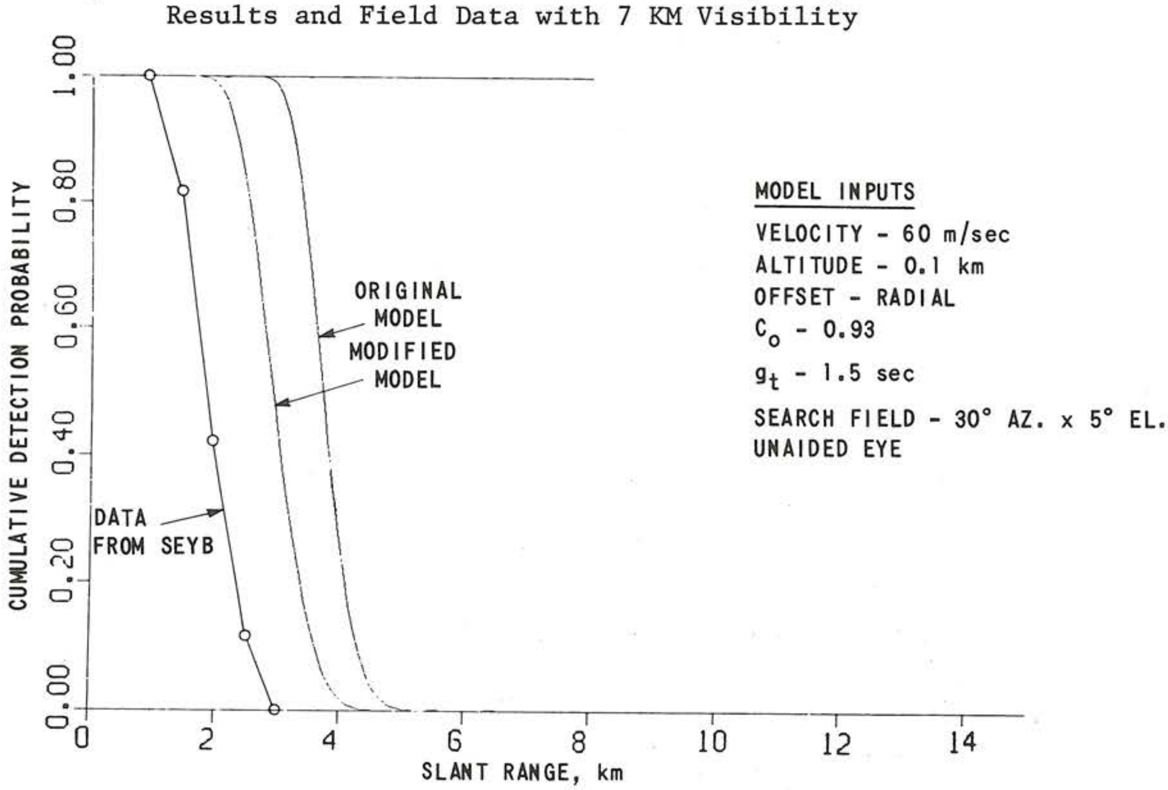


Figure 6b. Cumulative Detection Probability-Comparison of Model Results and Field Data with 5 KM Visibility

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APPENDIX A

The single glimpse detection probability ($\bar{g}$) is obtained by use of the relation:

$$\bar{g} = \int_0^{\pi} P(\phi_2'') \, g(M\phi_2'') \, d\phi_2'' \qquad \text{(A-1)}$$

where:

- ϕ_2'' = real difference angle between target position and fixation point*
- $g(M\phi_2'')$ = single glimpse detection probability
- $P(\phi_2'')$ = probability density of ϕ_2''
- M = magnification of optics (M = 1 for unaided search)

This appendix shows the procedure for generating the $P(\phi_2'')$ distributions as they depend on the independent distributions of target position and fixation point within a search field Ω_0. The situation is most easily understood by examining figure A-1. The two vectors representing target and fixation direction are unit vectors. All angles subscripted "1" are target coordinates, and "2" are fixation coordinates. The fixed frame x, y, z is that of the search field Ω_0.

*The difference angle ϕ_2'' is the same as θ' in the main text. As a matter of convenience, the notation used in this appendix and the main text were not forced to agree.

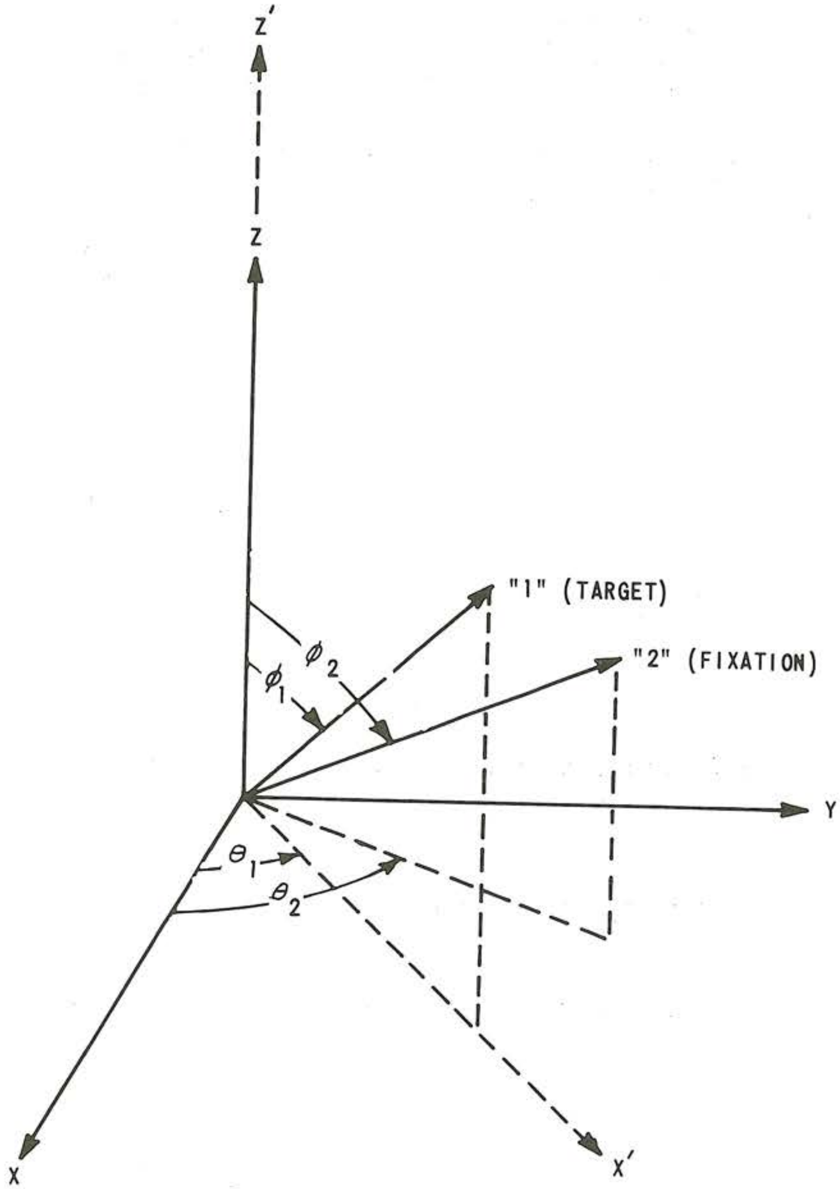

Figure A-1. Geometry of Target and Fixation Vectors

The distribution $P(\phi_2'')$ is found by integrating over the joint probability distribution of the two vectors. For a target vector within $d\Omega_1$, and a fixation vector within $d\Omega_2$, the joint probability can be written:

$$
\begin{aligned}
dP &= P_1(\theta_1, \phi_1)\, P_2(\theta_2, \phi_2)\, d\Omega_1\, d\Omega_2 \\
&= P_1(\theta_1, \phi_1)\, P_2(\theta_2, \phi_2)\, \sin\phi_1 \sin\phi_2\, d\theta_1\, d\phi_1\, d\theta_2\, d\phi_2
\end{aligned}
\qquad \text{(A-2)}
$$

where P_1 , and P_2 are the distributions of the target and fixation respectively.

We wish to integrate out three coordinates in such a way as to leave only the coordinate ϕ_2''. Since ϕ_2'' is not among the four coordinates of Equation A-2, it is first necessary to transform coordinates.

The transformation consists of a coordinate rotation to provide that the new z direction will coincide with the target vector, thus establishing that the new ϕ coordinate of the fixation will be the desired difference angle. The transformation is carried out in two steps. First is a rotation about the z axis through the angle θ_1 to place the target vector in a new x', z' plane:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & \sin\theta_1 \\ -\sin\theta_1 & \cos\theta_1 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} ; \quad z' = z \tag{A-3}$$

Second is a rotation about the y' axis through the angle ϕ_1, to finally put the target vector in the new z'' direction:

$$\begin{pmatrix} x'' \\ z'' \end{pmatrix} = \begin{pmatrix} \cos\phi_1 & -\sin\phi_1 \\ \sin\phi_1 & \cos\phi_1 \end{pmatrix} \begin{pmatrix} x' \\ z' \end{pmatrix} ; \quad y'' = y' \tag{A-4}$$

Since ϕ_2'' is the desired difference angle, we formally replace θ_2, ϕ_2 with θ_2'', ϕ_2''. Equation (1) thus becomes:

$$dP = P_1(\theta_1, \phi_1) P_2(\theta_2, \phi_2) \sin\phi_1 \sin\phi_2'' \, d\theta_1 \, d\phi_1 \, d\theta_2'' \, d\phi_2'' \tag{A-5}$$

Integrating over θ_1, ϕ_1 and θ_2'' yields the density $P(\phi_2'')$:

$$P(\phi_2'') = \sin\phi_2'' \int \sin\phi_1 \left\{ \int P_1(\theta_1, \phi_1) \left[\int P_2(\theta_2, \phi_2) \, d\theta_2'' \right] d\theta_1 \right\} d\phi_1 \tag{A-6}$$

where the integrals are taken over all space.* Before the inner integral can be performed, it is necessary to establish the relation between the old and new coordinates. That is, Equation (A-6) specifies θ_2'', ϕ_2'' and it is necessary to know θ_2, ϕ_2 in order to evaluate P_2. The components of the target vector in both systems are written:

$$\left.\begin{aligned} x'' &= \sin\phi_2'' \cos\theta_2'' & \qquad x &= \sin\phi_2 \cos\theta_2 \\ y'' &= \sin\phi_2'' \sin\theta_2'' & \qquad y &= \sin\phi_2 \sin\theta_2 \\ z'' &= \cos\phi_2'' & \qquad z &= \cos\phi_2 \end{aligned}\right\} \tag{A-7}$$

*The information regarding the search field (Ω_o) is formally included in the distributions P_1 and P_2.

Elimination of all the components between Equations (A-3), (A-4), and (A-7) gives:

$$\begin{pmatrix} \sin\phi_2 \cos\theta_2 \\ \sin\phi_2 \sin\theta_2 \\ \cos\phi_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\phi_1 & 0 & \sin\phi_1 \\ 0 & 1 & 0 \\ -\sin\phi_1 & 0 & \cos\phi_1 \end{pmatrix} \begin{pmatrix} \sin\phi_2'' \cos\theta_2'' \\ \sin\phi_2'' \sin\theta_2'' \\ \cos\phi_2'' \end{pmatrix} \quad \text{(A-8)}$$

or

$$\left.\begin{aligned} \sin\phi_2 \cos\theta_2 &= \cos\theta_1 \cos\phi_1 \sin\phi_2'' \cos\theta_2'' - \sin\theta_1 \sin\phi_2'' \sin\theta_2'' + \cos\theta_1 \sin\phi_1 \cos\phi_2'' \\ \sin\phi_2 \sin\theta_2 &= \sin\theta_1 \cos\phi_1 \sin\phi_2'' \cos\theta_2'' + \cos\theta_1 \sin\phi_2'' \sin\theta_2'' + \sin\theta_1 \sin\phi_1 \cos\phi_2'' \\ \cos\phi_2 &= -\sin\phi_1 \sin\phi_2'' \cos\theta_2'' + \cos\phi_1 \cos\phi_2'' \end{aligned}\right\} \quad \text{(A-9)}$$

The evaluation of $P(\phi_2'')$ in Equation (A-6) can now be carried out once the distributions (P_1 and P_2) are chosen.

It was attempted initially to assign uniform distributions to both P_1 and P_2 within the search field Ω_o and zero outside:

$$P_1 = P_2 = \begin{cases} 1/\Omega_o & (\text{inside } \Omega_o) \\ 0 & (\text{otherwise}) \end{cases} \quad \text{(A-10)}$$

Unfortunately, the evaluation of $P(\phi_2'')$ proved to be much too time consuming on the computer and the choice of Equation (A-10) was abandoned.

As an alternative it was decided to specify the target location within the search field thereby eliminating two of the three integrations in Equation (A-6). Formally, we write:

$$P_1(\theta_1, \phi_1) = \delta(\theta_1 - \theta_T, \phi_1 - \phi_T) \quad \text{(A-11)}$$

where δ is the Dirac delta function and θ_T, ϕ_T are the target coordinates. Equation (A-6) thus becomes:

$$P(\phi_2'') = \sin\phi_2'' \int P_2(\theta_2, \phi_2)\, d\theta_2'' \quad \text{(A-12)}$$

The reader should not be misled by the seeming absence of the target coordinates from Equation (A12) since they do enter into the required transformation of Equation (A-9).

SEMICONDUCTOR LASER APPLICATIONS TO MILITARY TRAINING DEVICES

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Systems using semiconductor gallium arsenide lasers have been developed in-house to train military personnel in M-16 rifle weapon firing against both pop-up targets and scaled model aerial targets.

The pop-up target system consists of two parts: (1) a miniature laser transmitter which clips on the barrel of an actual M-16 rifle, and (2) detectors and a receiver to score weapon hits. The system may be used to save ammunition costs, and to teach the correct sight picture, trigger squeeze, posture, and breathing techniques. The trainee also uses his own weapon so he becomes quite familiar with its feel. Because the laser system is eye-safe, no elaborate range safety precautions are necessary. Safe training can be accomplished in inhabited areas with these systems. Since the simulation unit can shoot in excess of one million shots on a small commercial battery, more training can be accomplished at a very low cost.

The gallium arsenide laser diode emits a 150 nanosecond flash of infrared energy and is eye-safe. The radiation is at a wavelength of 9050 Angstroms (near infrared) at $25^{o}C$. The laser output is four watts of peak power. The beam is collimated by a single, simple double convex lens, and the beam diameter at 300 meters is approximately 15 centimeters. However, the beam may be adjusted to a larger or smaller diameter. The laser which acts as a transmitter is powered by a small commercial 45-volt battery which is usable for in excess of one million shots. The unit can either emit a single flash, or shot, or simulate the weapon's firing rate for a 20 round magazine. When the weapon is fired the infrared laser pulses are detected by a large area silicon photodiode. In the pop-up target configuration, detectors are fastened to a standard M-31A1 Army pop-up target, which is a silhouette of a man. No changes are necessary to the pop-up mechanism to adapt it for use with this laser weapon fire simulator. The receivers have a field effect transistor, FET, front end and have a minimum of low cost components. The system has a range in excess of 500 meters in sunlight. In addition, this system can provide a record of score. The pop-up target system and laser transmitter attached to an M-16 rifle are shown in figure 1.

The aerial engagement trainer system is used to train military personnel to engage aerial targets. The trainer is used to teach squad members to detect and identify hostile aircraft, estimate the range, speed and direction of the target, proper alignment of the sight to obtain the correct lead, and to continuously track and engage the target.

The scores for an entire squad firing at the target can be electronically totaled. The target is a 1/12 scaled model aircraft that is equipped with several silicon photodetectors. Lead angle is incorporated in the laser transmitter system by a mechanical swivel, which offsets the gallium arsenide laser transmitter at the lead angle which corresponds to the speed of the scaled model. The transmitter fires at the cyclic firing rate of the M-16 weapon and simulates the number of rounds in the weapons magazine. In the aerial engagement model, the laser transmitter beam is shaped with an aperture or stop to a rectangular geometry. The rectangular beam enables the use of fewer photodiode detectors on the target. An electronic counter is used to score the number of hits on the target. A special feature to allow the student to get the proper sight picture for the various lead angles has also been incorporated. A Xenon flasher is located in the model's cockpit; when the student has the correct lead, the flasher is activated. This enables the student to see the correct sight picture for the various aircraft speeds prior to firing at the scaled moving target. The aerial engagement system is shown in figure 2.

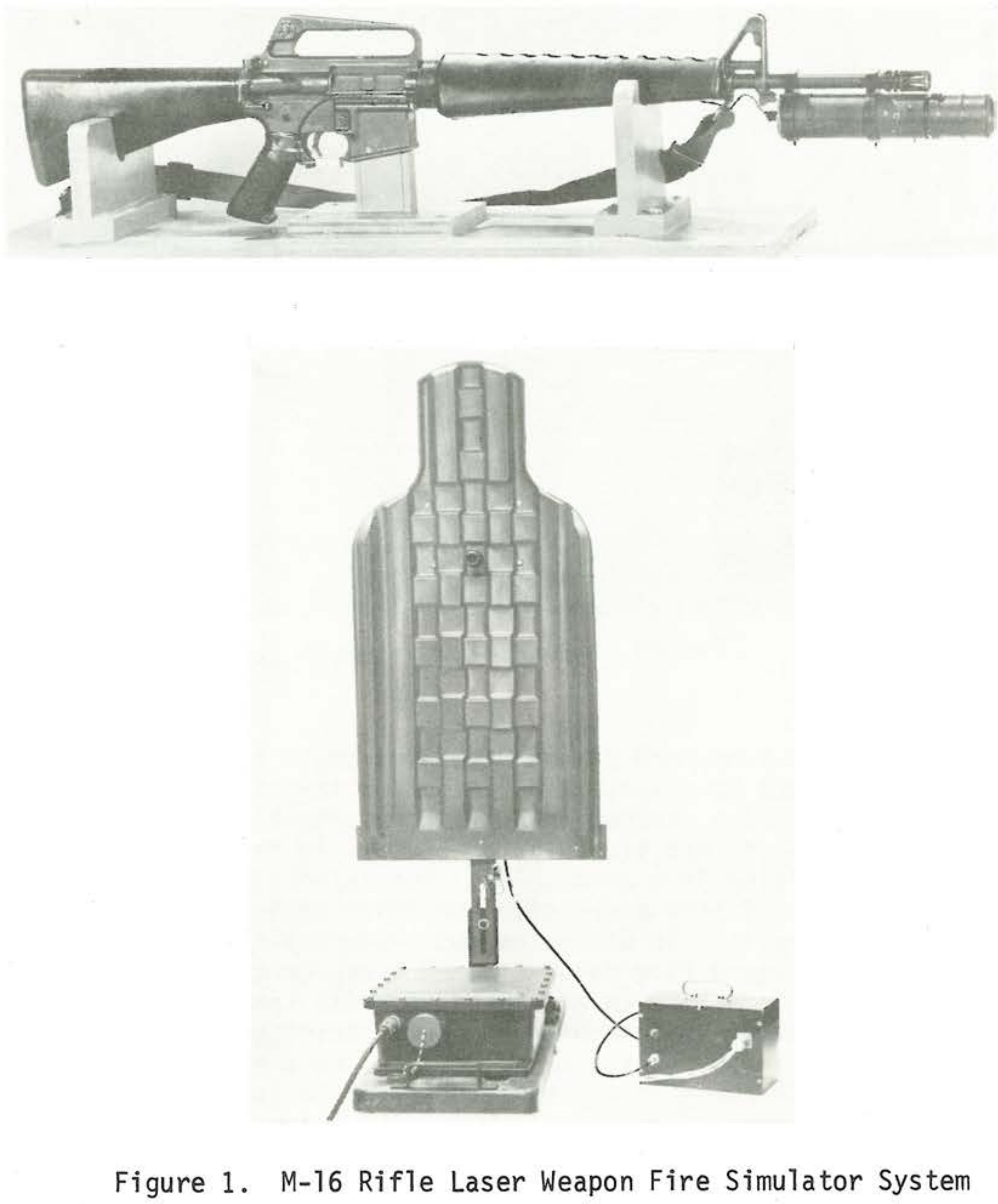

Figure 1. M-16 Rifle Laser Weapon Fire Simulator System

Figure 2. Aerial Engagement System

A study was performed at the U.S. Army basic training center at Fort Jackson, South Carolina, with the pop-up target system, to determine the effectiveness of a marksmanship training program of instruction using the laser weapon fire simulator as opposed to the present program of instruction utilizing live ammunition. The objective was to determine which combination of live ammunition and laser training will give the best training results. To determine the best results, scores on the live ammunition record fire range of each group were compared. Figure 3 shows the results. Notice in all cases recruits trained with the laser did as well, or better than soldiers trained exclusively with live ammunition, which costs six cents a round. It has been estimated that six million dollars in ammunition costs alone will be saved each year using this training device.

A moving target system using a semiconductor laser is now under development. In this system both the laser transmitter and a receiver are attached to an actual M-16 rifle. A corner mirror or retro-reflector is attached to the moving man target. When the rifle is fired, an eye-safe laser pulse of near infrared energy is transmitted.

If the trainee's sight is on the target, the retroreflector will return most of the energy directly back to vicinity of the transmitter and receiver, even if the retroreflector is not directly on axis to the transmitter. The received pulse is amplified and actuates a tone indicating a hit. The batteries and a small speaker are in the rifle's magazine. The retroreflector is placed in front of the man or dummy so that it will be necessary to lead the man to get a hit. If the dummy moves at varying speeds, apertures are used to shutter or unshutter the appropriate retroreflector. The trainee gets instant scoring without complicated radio links to relay back the firing results. In this system the retroreflector requires no target maintenance; it only needs to be kept reasonably clean. At closer ranges high gain materials can replace the retroreflector. This system allows programming for the dummy to move at various speeds. The system is safe and requires less range personnel to operate than a standard rifle range, and saves the cost of ammunition.

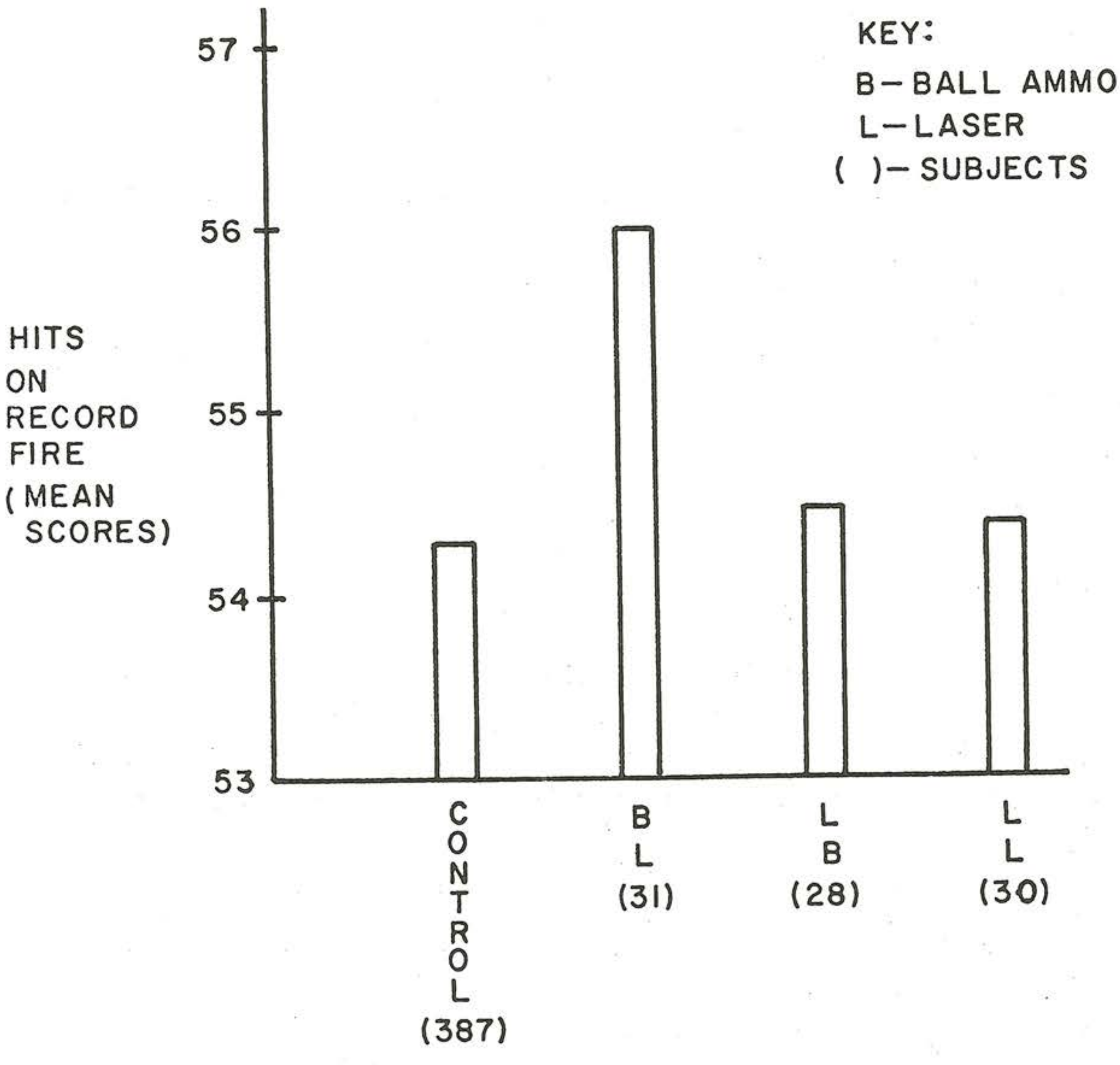

Figure 3. Results of Laser Rifle Transfer of Training Tests at Ft. Jackson, S.C.

DIGITAL RADAR LAND MASS DISPLAY SIMULATION

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SUMMARY

Simulation of radar Plan Position Indicator (PPI) displays is a critical requirement in training navigators, pilots, and bombardiers to identify targets and to interpret radar return signals from terrain and cultural areas. Present radar land-mass simulators use a transparency data base read by a flying spot scanner. This approach is limited by the difficulty in preparing the transparencies to meet the required resolutions and by the difficulties in updating transparencies to reflect cultural changes such as new bridges, large buildings, piers, and other features that are prominent in a radar display and that are key factors in training a pilot, navigator, or bombardier to quickly recognize his target and position.

The Digital Radar Land-Mass (DRLM) approach solves the resolution and flexibility problems. In the digital approach, terrain and cultural features are reduced to a mathematical representation, such as line segments, and are stored in a digital memory. A radar sweep is defined. Representative radar return signals are calculated, based on the digitally stored data, and then are displayed on a PPI radar scope.

An experimental laboratory model Digital Radar Land-Mass Display Simulator was developed and evaluated. Terrain and cultural features (boundaries) were represented as line segments, digitally defined and stored by the Cartesian coordinates (x, y, and z) of the line end points. Based on aircraft position, a general-purpose digital computer defines a radar scan area and transfers the area data lines to a high-speed core memory. This memory is read once per sweep (PRF) by a special high-speed digital processor that selects the data lines intersected by the sweep and determines the point of intersection. The intersections are then ordered relative to increasing ground range (the sweep profile) and applied to a video processor, which modulates the profile for radar and other effects (shadow, incidence angles, earth curvature, etc.), and develops an intensity modulated sweep signal that is displayed on the PPI. The system processing rate is a line per microsecond. Thus, the system has a basic capability of processing 4000 data lines per real-time (4-millisecond) sweep.

The PPI display resulting from the laboratory system is shown in Figure 1. This is a time exposure of a real-time PPI scan. The scan rate is 14 scans per minute. Aircraft altitude is 14,000 feet and the sweep range is 45 n. mi. The data base for this display uses 4000 data lines to define reflectivity boundaries of cultural areas; such as, San Francisco, Berkeley, Oakland, San Jose, etc., and to define terrain elevation features such as the Santa Cruz and Diablo mountain ranges, Mt. Diablo, Mt. Tamalpais, etc. The data base also has 1000 data points that represent radar point source targets; such as, radio towers, buildings, ships, storage tanks, etc. The system allows complete freedom of motion over the data base in real-time. Elevation can be varied from zero to 30,000 feet, and the display accurately depicts radar shadow slant range effects, incident angle effects and shadow.

The conclusions of this project were: (1) the digital approach provides a cost-effective means for achieving the flexibility and resolution required in radar operator training simulators; (2) the ridge/valley and cultural boundary line approach provides a realistic three-dimensional real-time display capability; and (3) the line approach provides a significant reduction in the amount of data that must be stored and processed for a whole training mission.

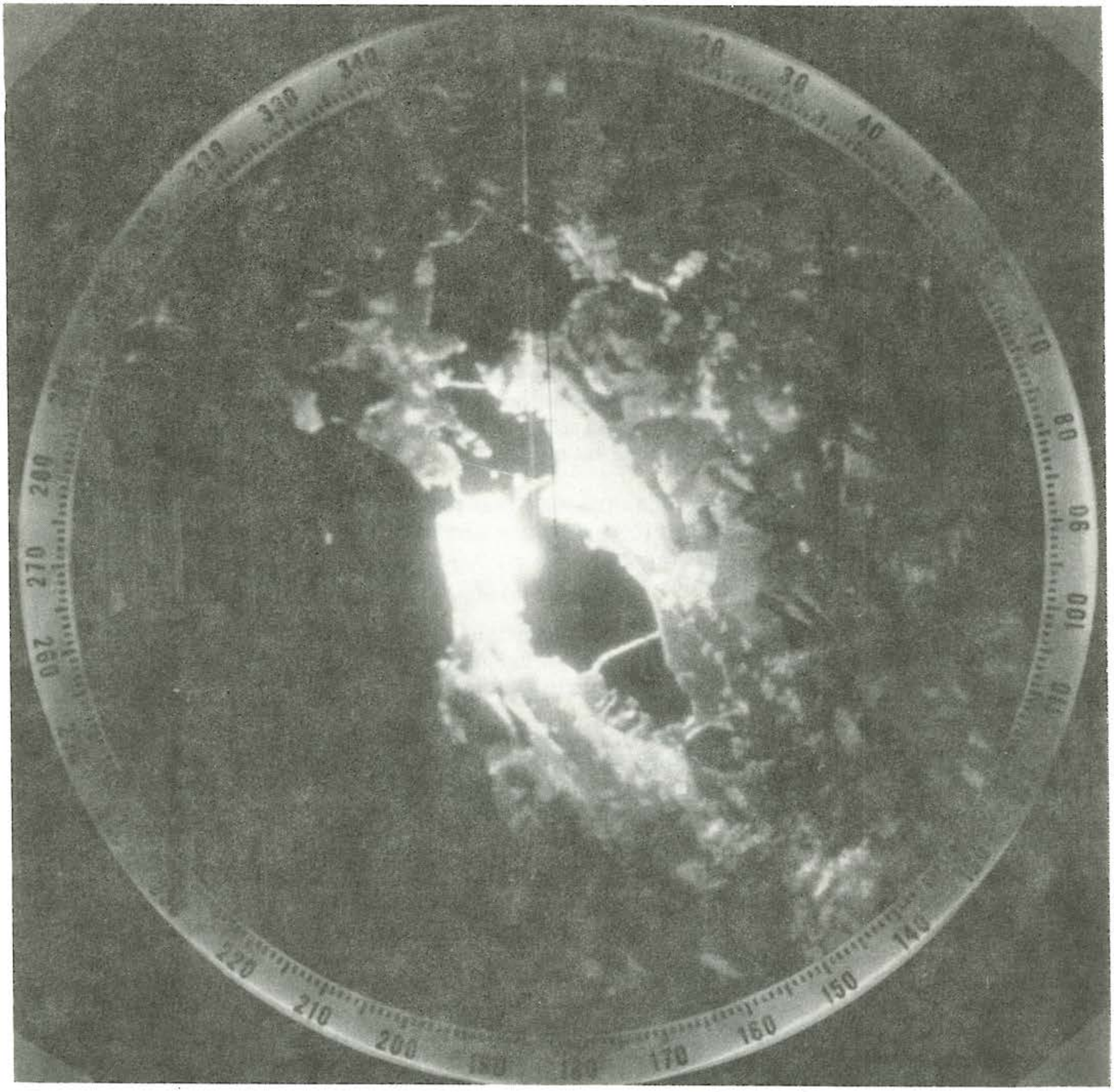

Figure 1. The San Francisco Bay PPI Display

MATHEMATICAL MODEL AND DEFINITIONS

Terrain and cultural features are represented in the data base by contiguous line segments defined by the x, y, and z of their end points. Each line segment (figure 2a) defines a boundary between areas of different radar reflectivity and/or a terrain ridge or valley line. The reflectivity and radar texture code (Codes A, B, and C of figure 2a) for the right side and the left side of each line, as one goes from point to point through the data base, is stored with each line segment. Targets are points source features (smaller than radar beam width) that have a high reflectivity. Examples are ships, oil tanks, buildings, transmission line towers, etc. These are stored as independent points (x, y, and z) along with a code that defines target size and reflectivity.

A scan is defined as the complete picture seen by the radar from its current position. A sweep is one line of a scan and is identified with the radar pulse return signal. Assuming an aircraft ground position of x_A and y_A relative to a data base and a sweep line as defined by cos θ and sin θ, then the distance of the n^{th} data point from the sweep line (figure 2b) is

$$d_n = (y_n - y_A) \cos\theta - (x_n - x_A) \sin\theta. \tag{1}$$

The ground range from the sweep origin (x_A, y_A) to the intersection of the distance vector, d_n, is

$$R_{gn} = (x_n - x_A) \cos\theta + (y_n - y_A) \sin\theta. \tag{2}$$

The relative signs of d_n and d_{n+1} define when the sweep line intersects a data line (i.e., opposite signs indicate an intersection while the same signs indicate a no hit). The ground range to the intersection and the elevation of the intersection are determined by linear interpolation using d_n and d_{n-1}.

The sign of d_n also defines the direction that the sweep line crosses a data line. The reflectivity and texture on each side of a data line have been consistently coded right and left as we go from point to point. Thus, a positive d_n tells us that the right-hand code should be initiated—while a negative d_n specifies the left-hand code.

A target processor solves the same equations for d_n and R_{gn}. A target echo is generated when the sweep line passes within a half beam width of the target. This is defined by detecting when d_n is within a graduated band pass around zero.

The intersection points, when ordered relative to increasing ground range, describe an elevation and code change sweep profile as illustrated in figure 2c. Points 1, 2, 3, etc., are intersections or targets, and each point has encoded a ground range, elevation, and a reflectivity or texture change.

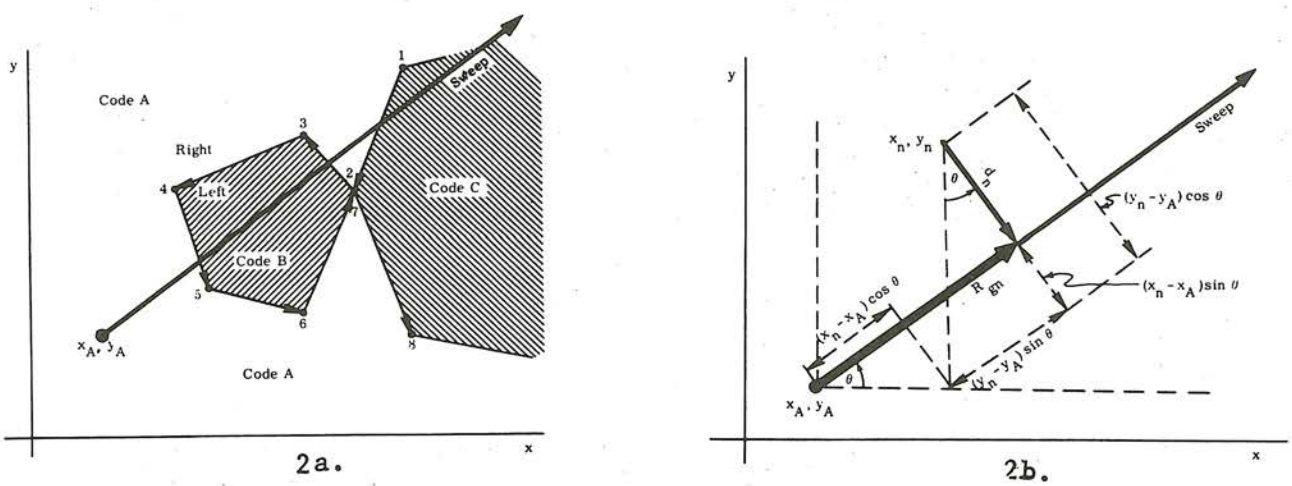

Figure 2a. and 2b. System Geometry

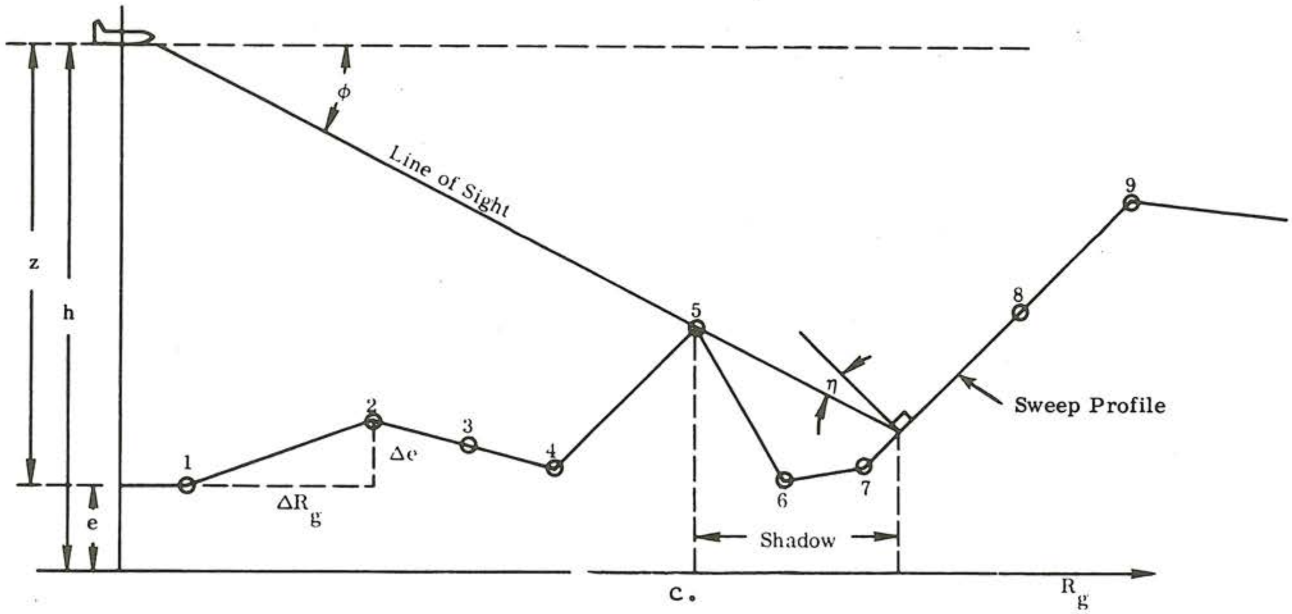

Figure 2c. System Geometry

The intensity of a radar return signal will be a function of the reflectivity of the surface (this is the stored data) and the angle of incidence between the surface and the look angle ϕ. The intensity will vary as the cosine of the incidence angle η of figure 2c.

$$\cos \eta = \frac{(h - e)\, \Delta R_g + R_g\, \Delta z}{R_s\, M} \tag{3}$$

where

$$M = \sqrt{\Delta R_g^{\;2} + \Delta z^2}$$

Earth curvature must be accounted for. The change in terrain elevation as a function of earth curvature is approximately

$$\Delta z_e = \frac{R_g^{\;2}}{2\, \rho} \tag{4}$$

where R_g is ground range and ρ is the mean earth radius.

The radar return signal position on the PPI is a function of slant range—not ground range. The slant range is

$$R_s = R_g \cos \phi + (h - e) \sin \phi \tag{5}$$

Radar shadow is an area where there is no return signal. In figure 2, this is the area between point 5 and where the beam strikes the surface between points 7 and 8. The intensity is zero. The start of a shadow is defined by an increase in the angle ϕ as one progresses from point to point along the sweep profile. The end of a shadow is indicated by the point where ϕ becomes less than the value at the start of the shadow.

Finally there is a number of special radar effects that were not simulated in the present system. Some of these are: (1) Radar beam width integration; (2) specular surface returns; (3) pulse width integration; and, (4) directional targets. In general, these effects can be readily derived from the geometry defined previously.

THE LABORATORY SYSTEM

Figure 3 is a block diagram of the laboratory breadboard system that was developed to prove the feasibility of a real-time radar display system based on the approach described in the preceding section. A manual input control, "joy stick," defines the location, elevation, heading, and velocity of the aircraft. A small general purpose digital computer then selects from the region or training data base, stored on a disc file, the data lines and targets seen by the radar scan and loads these into one of two scan memories—one memory is being read while the other is being loaded with data for the next scan.

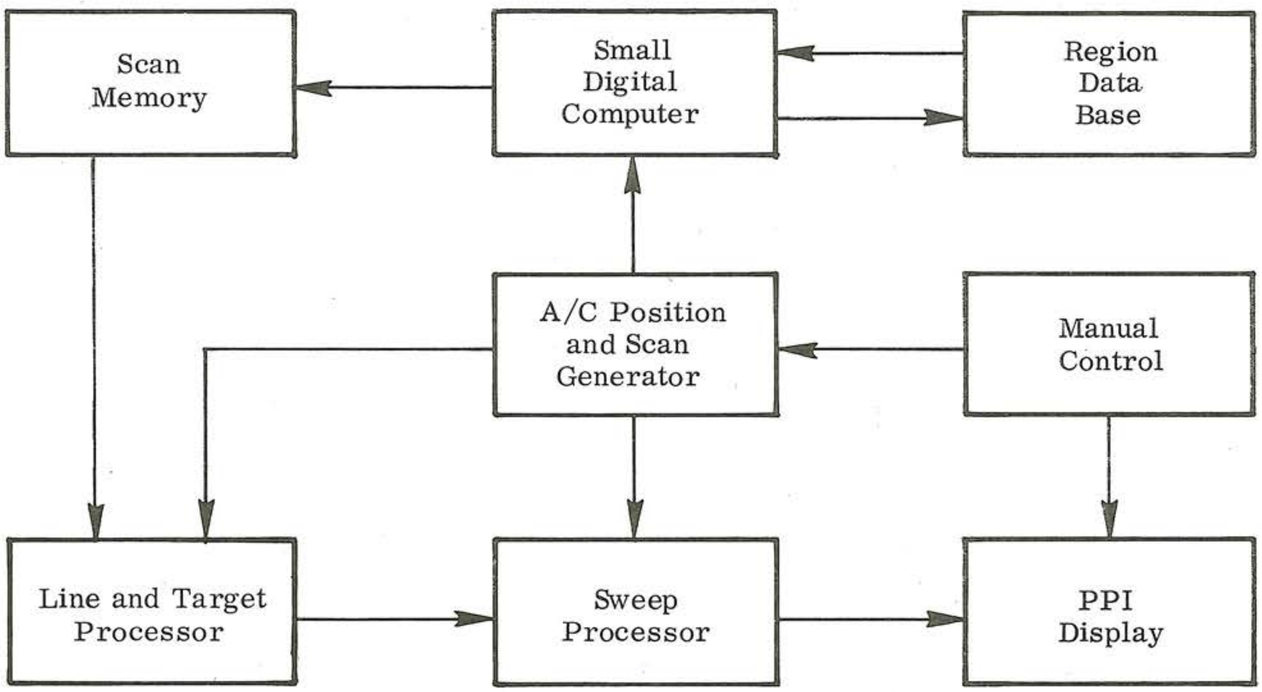

Figure 3. The Laboratory System

The line and target intersection processor reads the scan memory at a point per microsecond and computes the sweep profile, figure 2c. This unit is a special high-speed dedicated digital processor that employs parallel and pipeline processing techniques. The processing technique is illustrated in figure 4. In the first microsecond, a data point and sweep data are read in and corrected for aircraft position. In the next microsecond, d_n and R_{gn} (Equations 1 and 2) are computed. If the data line intersects the sweep, the ground range and elevation of the intersection are determined by an interpolation process which also takes one microsecond.

Targets in the current laboratory system are processed in a parallel unit in a similar manner. The interpolator unit is not required in the target channel because when d_n is within a graduated band about zero, a hit is scored and the computed range is the true ground range.

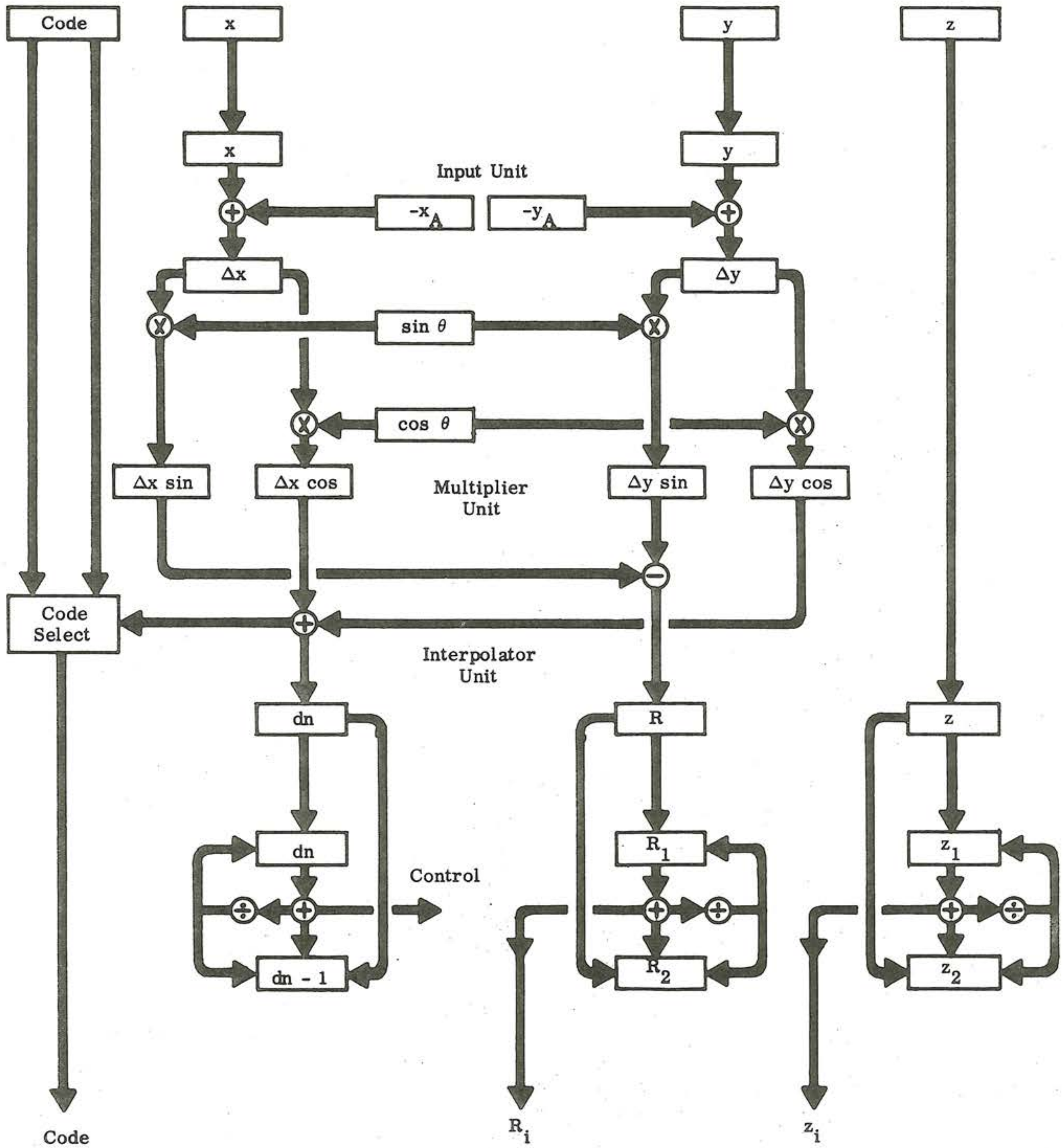

Figure 4. The Line and Target Processor

The outputs are then ordered relative to ground range by reading the code and elevation data into a random access memory using ground range as the address. Again two memories are used—one is receiving and ordering data while the other, which contains the previous sweep data, is being read by the sweep processor.

In the sweep processor, figure 5, a ground range counter reads out the sweep profile from the output memory of the line and target processor. In the current laboratory system, the sweep processor is a high-speed dedicated analog unit. This is currently being replaced by an all-digital unit. The digital sweep profile is converted to an analog profile and earth curvature, slant range, incident angle, and shadow effects are computed. The multiplication, division, and modulator functions are accomplished with variable transconductance multipliers having a full power bandwidth of greater than one megacycle.

The psuedo-noise generator is a closed-loop shift register that generates a psuedo-random sequence of ones and zeros. Different texture effects are achieved by varying the sequence frequency. The P-N code, when read out of the memory, will gate in one of three codes. With each output is a 3-bit digital word that defines the radar reflectivity level. The P-N sequence is modulated by the product of the reflectivity level and cos η in the video modulator. The output of the modulator is the PPI video intensity signal.

The computed slant range, R_δ, is multiplied by sin θ and cos θ providing the x and y deflection voltages of the sweep. Thus the sweep is driven directly by slant range and simulates integration and inversion effects.

CONCLUSIONS

Prior to the start of the DRLM effort, it was known that a digital approach would provide the advantages of flexibility and ease of modifications mentioned in the Summary. In addition, it was recognized that the digital approach could provide a very significant improvement in reliability and in maintenance cost reductions in comparison with the current analog systems. The question that had to be answered was, "Can the digital representation of the terrain and the computations required to produce an accurate, realistic, real-time radar display simulation be performed in a cost-effective manner?" The results of the effort provide a fully verified "Yes" as the answer to this question.

The PPI display resulting from the current laboratory system is adequate for some training missions. However, many training missions will require a display of higher density and resolution. A laboratory development program is now underway that will provide a factor of improvement greater than ten over the current system. First, a data input filter is being developed that will allow an input data density of 16,000 lines or targets per scan. Second, a digital sweep processor is being developed that will divide a one millisecond sweep into 1000 elements and compute slant range, incidence angle, shadow, and earth curvature for each element. The current laboratory system is limited to 4000 lines and targets per scan and 512 elements on a 4 millisecond sweep. The improved system will use the same processing techniques and current state-of-the-art logic units as are used in the current system.

Special processors for beam width integration, specular returns, directional targets, and other radar effects are being implemented. With these improvements, it is predicted that the Digital Radar Land Mass approach can meet all radar operator training requirements.

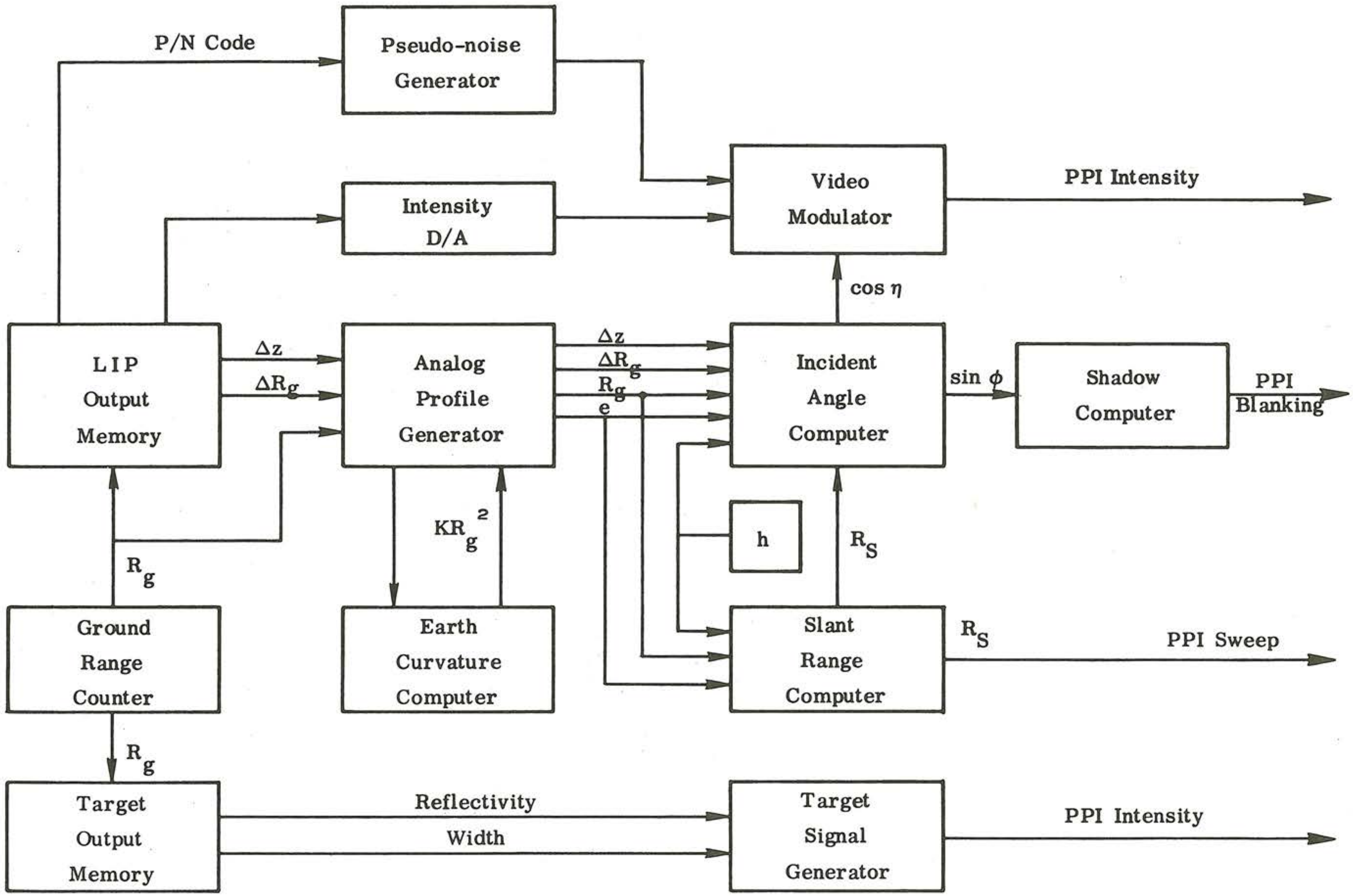

Figure 5. The Sweep Processor

DESIGN AND PRODUCTION OF ANTIREFLECTION COATINGS

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Multilayer thin films are widely used in science and industry for control of light. Optical surfaces having virtually any desired reflectance and characteristics may be produced by means of thin film coatings. These films are usually deposited on substrates by high vacuum evaporation. The applications range from high reflectance laser mirrors to high transmittance optical systems including interference filters, hot and cold mirrors, broad band reflectors and narrow band reflector, all of which are used in visual simulation systems and training devices. This paper will be concerned with the design and production of multilayer, dielectric, antireflection coatings for use in the visible spectrum from 400 to 700 nanometers.

Everyone who has seen colors exhibited by films of oil on water, and by soap bubbles, has observed the striking phenomena of interference in thin dielectric films. Interference in layers having fractional wavelength optical thicknesses remained a scientific curiosity until the 1930's when methods were developed for depositing one or more layers of solid dielectric of controlled thickness. The most common technique consists in vaporizing the dielectric in an oven, placed in a highly evacuated vacuum chamber, and condensing the vapor on the relatively cool surface of the substrate. Layer after layer of different materials of any desired optical thickness can be deposited in this way. The performance of dielectric thin film coatings is predicted well by a theory to be described later, which treats each layer as a homogenous medium, with sharply defined plane boundaries.

The nomenclature for a three-layer thin film coating is illustrated in figure 1. The n's are the five indices of refraction of the various media involved (the three layers plus the medium and substrate). The L's are optical thicknesses of the three layers (the medium and substrate are assumed to have infinite thickness). An optical thickness is simply the product of the physical thickness and the material's index of refraction. Note the S and P indicated on the incident wave; they are representative of polarization perpendicular or parallel respectively to the plane of incidence. The reflectance is the square of the absolute magnitude of the amplitude ratio of the reflected wave over the incident wave.

The numerical values of the reflected and transmitted wave amplitudes are governed, in general, by the boundary conditions on Maxwell's equations. More specifically, Fresnel's equations, which apply to the dielectric case, lead to a matrix formulation of thin film theory which lends itself very well to the computation of multilayer problems. The pertinent matrix relationships for normal incidence are given in figure 2.

In figure 2, M is the transfer matrix of the entire multilayer coating, r and t are the reflection and transmission coefficients,

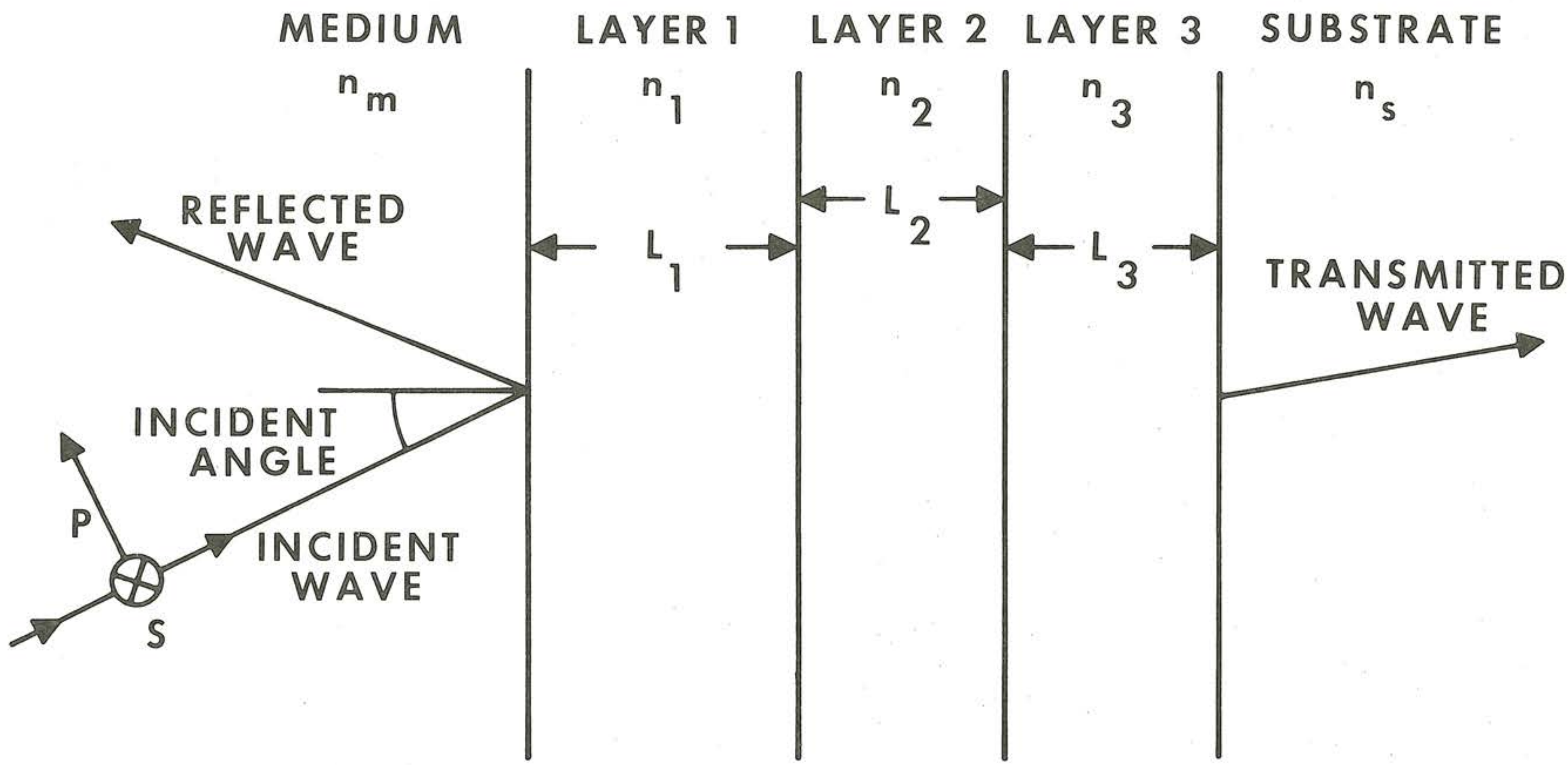

Figure 1. Schematic of Three-Layer Coating.

M_I is the transfer matrix of layer i, j is the square root of minus one, L_i is the optical thickness of layer i, and λ is the vacuum wavelength of the incident light.

Consider a system comprised of N layers. The problem is to find the reflectance at vacuum wavelength λ. Assuming the optical thicknesses are known the matrices MI can be obtained and subsequently the transfer matrix of the entire thin film system by simple matrix multiplication -- M_1 times M_2 times M_3, etc. times Mn. Substitution of M into equation 1 yields a known relation between r and t, the reflected and transmitted amplitudes. Another relation relating r and t is that $|r|^2 + |t|^2 = 1$ assuming no absorption. Using these two relations, a value for reflectance can be calculated.

For other than normal incidence the equations become more complex. The effect of incoming polarization must be taken into account as well as the angle of refraction at each surface boundary. Rather than repeat tedious calculations, I will just state that I have written a simple program for our programmable desk calculator, which can compute the reflectance from up to three-layer thin films, for incoming light of either S or P polarization at any angle of incidence. The program is designed to compute reflectance for wavelengths from 400 to 700 nanometers in 10 nanometer steps. The results, together with the input data, are printed out in tabular form.

Figure 3 is a sample printout which just repeats the input data. Figure 4 contains several curves drawn from data supplied by the calculator printout. The curve marked "Glass" is the expected constant 4% reflectance from a dielectric of index 1.5. Note no effort has been made to include dispersion or absorption in any of these or the following computations. The MgF_2 curve is the spectral reflectance as computed for a single 125 nanometer thick coating of index 1.38 on substrate of index 1.5. The triple layer curve is the reflectance for 125 nm MgF_2 index 1.38 + 250 nm Nd_2O_3 index 2.00 + 125 nm CeF_3 index 1.60 on glass of index 1.50.

Figure 5 contains similar curves where the material and thicknesses are the same as the triple layer coating on the previous slide, but angle of incidence and incident polarization have been varied. Note that reflectance of uncoated glass at 30^o S polarization is 5.77% and at 60^o P polarization is 0.18%. Obviously you are not always better off with AR coatings. Another point of interest, which is not immediately obvious from these curves, is that the region of lowest reflectance shifts toward the shorter wavelengths as the angle of incidence increases. This, by the way, is also true of narrow band interference filters.

The production of these coatings involves the deposition of controlled thicknesses of various materials on the desired substrate. Fortunately the thickness of each layer can be monitored individually without breaking the vacuum. In figure 6, the reflectance as a function of single layer film thickness for a single wavelength is plotted. The upper curve is for a film of higher index than the substrate and the lower curve is for a film of lower index than the substrate. The important characteristic of these curves is not so much the absolute

$$1.\quad \begin{bmatrix} 1 \\ n_m \end{bmatrix} + \begin{bmatrix} 1 \\ -n_m \end{bmatrix} r = M \begin{bmatrix} 1 \\ n_s \end{bmatrix} t$$

$$2.\quad M = \prod_{i=1}^{N} M_i$$

$$3.\quad M_i = \begin{bmatrix} \cos 2\pi L_i/\lambda & -j\frac{1}{n_i}\sin 2\pi L_i/\lambda \\ -jn_i \sin 2\pi L_i/\lambda & \cos 2\pi L_i/\lambda \end{bmatrix}$$

Figure 2. Equations relating Reflection and Transmission of a Multilayer Coating

THREE LAYER COATING

n_m = 1.000

n_1 = 1.380

n_2 = 2.000

n_3 = 1.600

n_s = 1.500

ANGLE 60.00

POLAR 1.0

L_1 = 125.00

L_2 = 250.00

L_3 = 125.00

Figure 3. Sample Input Data Reprinted by Desk Calculator.

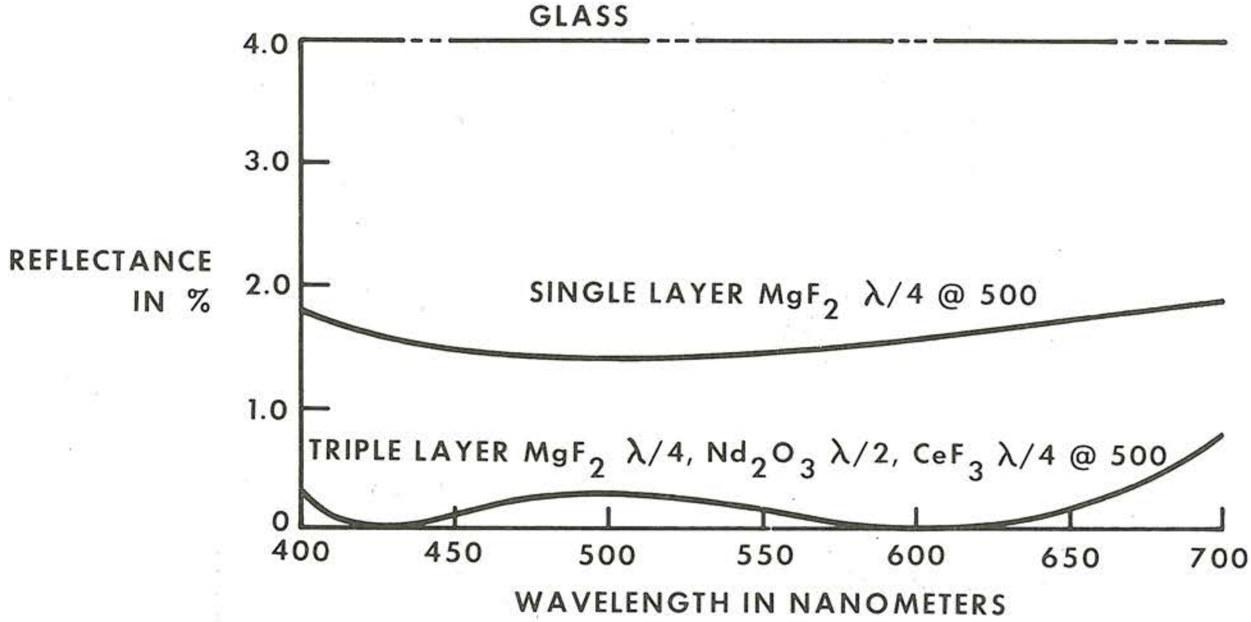

Figure 4. Reflectance as a Function of Wavelength at Normal Incidence.

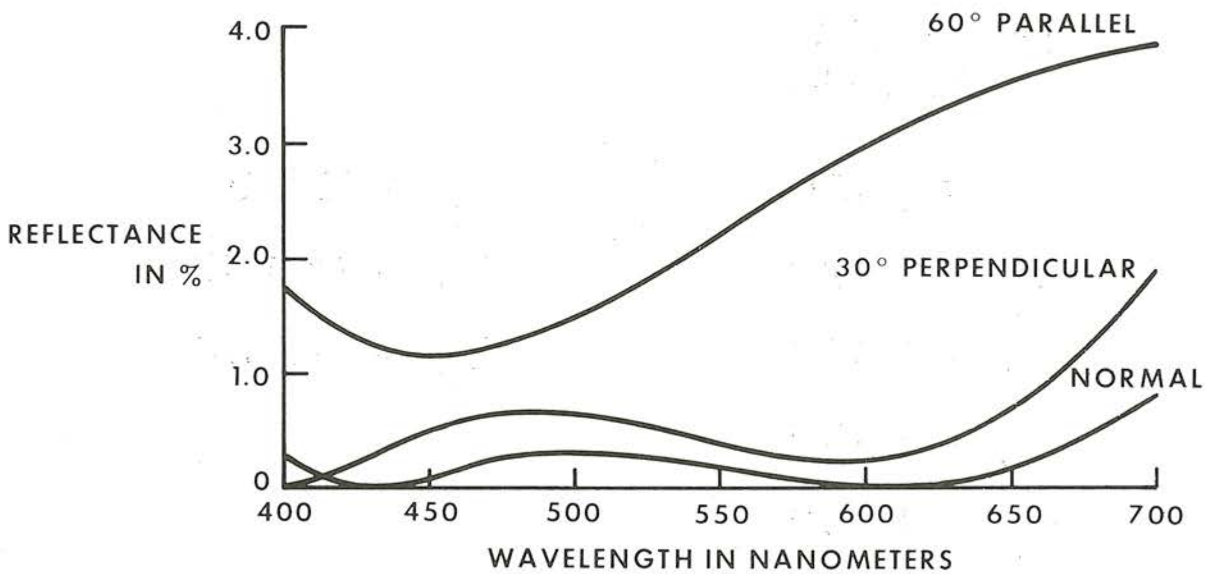

Figure 5. Spectra Reflectance as a Function of Angle of Incidence and Polarization.

value of the reflectance but the fact that they periodically reach maxima and minima. Therefore, if each layer is deposited on a test plate, the reflectance can be measured continuously at the design wavelength, while the coating is taking place, and the coating process can be stopped when the desired optical thickness is reached. If other than quarter wave multiples of thickness are desired, the monitoring wavelength can be changed to other than the design wavelength where the thickness would be in multiples of quarter wavelengths. In figure 7, the monitoring system which we were designing and installing at the time this paper was written, is pictured. Note that the test piece is apertured so that only the area being looked at by the viewing system is exposed to the coating material. As different materials are coated the test piece is manually rotated to expose a clean area. The substrate is continuously rotated off-center to allow uniform deposition during coating. We expect to achieve uniformity in optical thicknesses to 0.05% (1 Angstrom). Rotating offset fixtures are the only way to achieve this uniformity using thermal source with non-uniform distribution. The height of the substrate above the source should be approximately 25 cm with a 17 cm offset to center of substrate. The maximum non-uniformity will then be a linear function of the number of revolutions. Trade-offs on coating time and maximum RPM of substrate lead to an ideal coating time of approximately 2 minutes per layer. The test piece should be placed such that the area being coated has the same geometry as the center of the substrate. By having several sources available for deposition, many layers can be coated without breaking vacuum.

The application of multilayer thin film antireflection coatings in visual simulation systems and displays are many. The desire for high luminance, high contrast displays generated by many surface optical systems is satisfied in two ways by antireflection coatings. The first obvious effect is the increase of total light transmitted through the optical system. The second, not so obvious, effect is the suppression of out of focus ghost images which tend to degrade both the contrast and overall optical quality of the image. A straightforward calculation, assuming normal incidence at each surface, for a 32 surface optical train yields a transmission of 27% for uncoated glass, 62% for single layer MgF_2 coatings, and 94% for the specific three layer coating discussed above.

Our experimental investigations are presently directed toward durable antireflection coatings on low index substrates such as plastics. As of the time this paper was written, several experimental runs had been made with one, two, and three layer coatings. Since our results were incomplete, they are not reported in this paper.

Future work will also be directed toward programming up to 50 layers and production of laser mirror coatings, hot and cold mirrors, and narrow band interference filters.

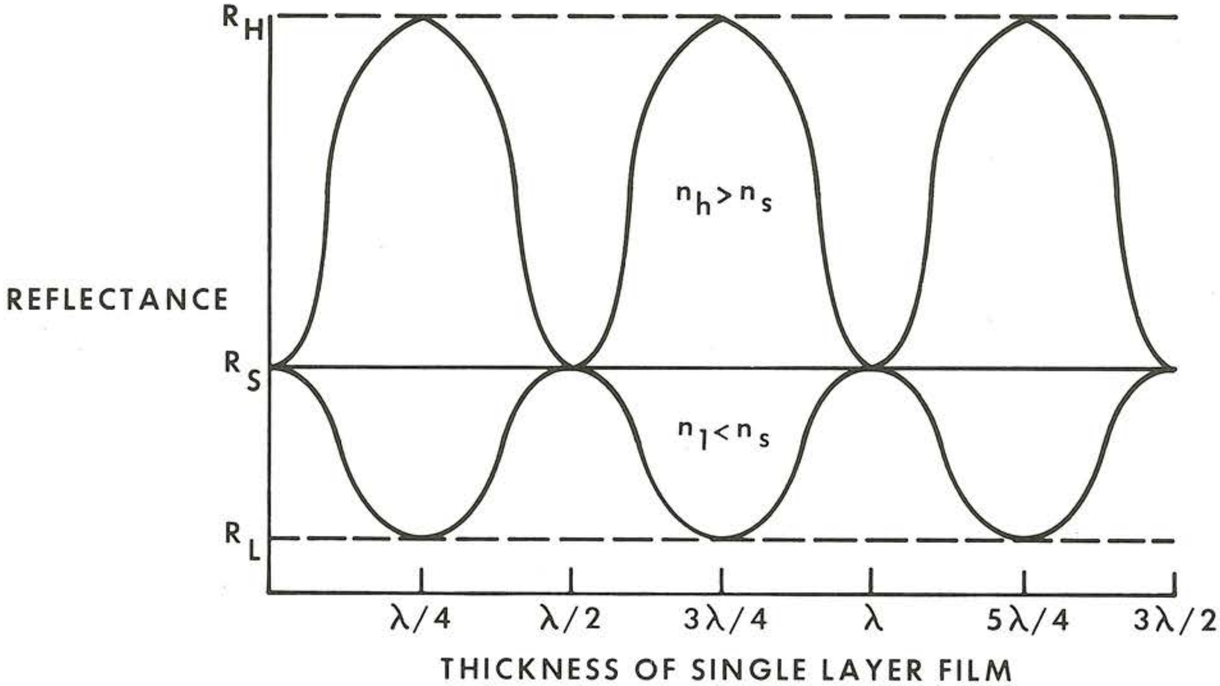

Figure 6. Reflectance as a Function of Thickness of Single Layer.

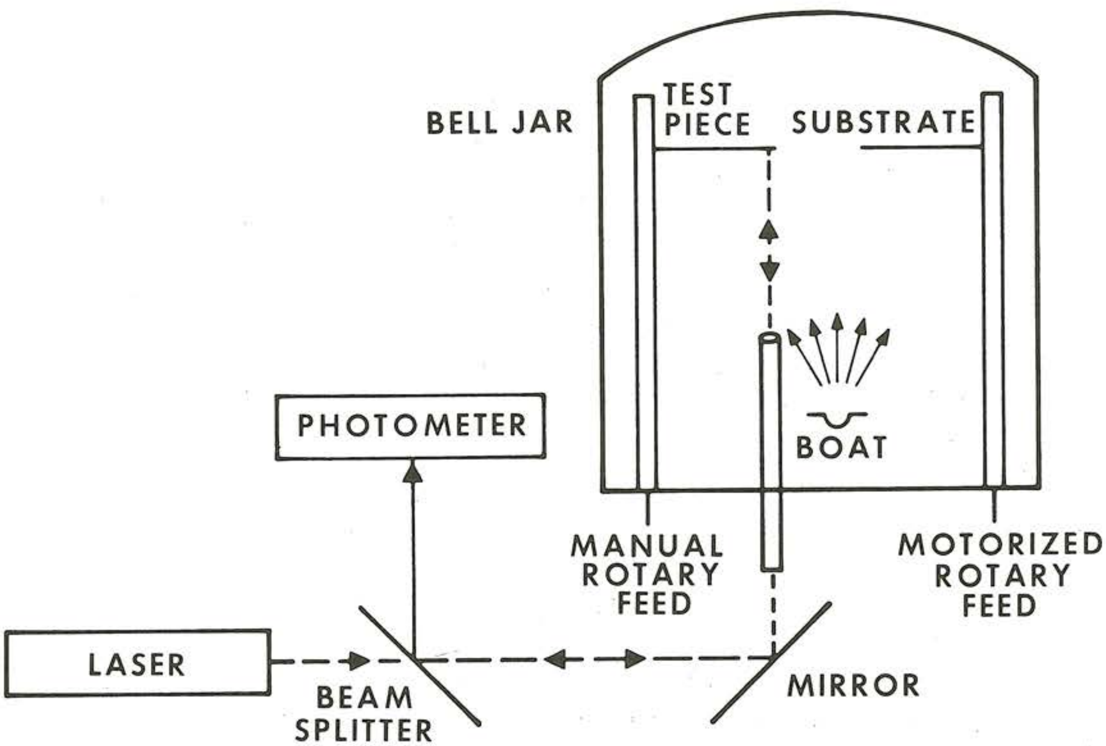

Figure 7. Film Thickness Monitoring System.

140° CLOSE APPROACH OPTICAL PROBE FOR VISUAL SIMULATION

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ABSTRACT

Optical pickups for flight simulators using TV displays have depth of focus limitations at close approaches to the model surface. Tilt focus corrected optical probes have been developed in recent years to overcome this problem while maintaining relatively large entrance pupils. Thus diffraction limitations and lighting problems associated with the pinhole approach are avoided.

A new 140° circular field tilt-focus (Scheimpflug) probe has been developed that can operate to 0.2 inches altitude with an entrance pupil of 1 mm diameter. The single channel device has a 17 mm diameter sensor format.

High resolution levels have been obtained over most of the field and altitude range with a relative aperture of T/10.5. The engineering feasibility model developed has full functional capability using hand-operated controls.

The study and development was performed by the Farrand Optical Co., Inc. New York, under the auspices of the USAF Human Resources Lab., Wright Patterson Air Force Base, Dayton, Ohio

A fully automated model is currently under development.

INTRODUCTION

In the past decade we have seen fairly dramatic improvements in training simulation - particularly in the visual area. The recognition of the value and cost-effectiveness of simulators has paralleled the development of vastly more complex and costly aircraft and space vehicles. A host of recently developed simulation devices such as infinity displays, CCTV and Film image generation systems along with the advances in computer technology now provide a wide array of components for future systems.

The 140° field close approach optical probe is an example of a new basic component tool that will hopefully extend the possibilities of the CCTV-model approach to visual simulation.

USE OF OPTICAL PROBES IN SIMULATORS

An optical probe or pickup is essentially a specialized closed-circuit TV camera lens. As typically used in a visual simulator for flight training, the probe becomes the pilot's eye and airplane. It views the scale model scene and is "flown" over the model at scale speeds and altitudes via its gantry motion capability. (Sometimes, altitude is controlled by model motion while the gantry supplies latitude and longitude). Pitch, roll and yaw are usually provided by the probe itself. Use of a computer controlled miniature prism scanning head allows excellent dynamic response.

Optically, the probe differs from normal lenses in a number of respects, posing a number of unusual design problems. The most serious stems from the requirement that the simulated pilot eyepoint be placed as close to the simulated runway as possible. This is necessary so that reasonably sized models can be employed for fly around and landing simulation. Thus close approach capability is a critical factor in designing a complete simulator facility by allowing more favorable trade-offs between facility and model size (cost) and operating range. A large entrance pupil is also significant here in reducing model lighting complexities and costs.

Of course, close approach capability must be combined with other favorable optical parameters to achieve a successful and economical system: high resolution, wide field of view, low distortion, and a fast relative aperture. The optical system must also be properly mated to the sensor and visual display output so that proper perspective is observed in the complete simulator system.

THE DEPTH OF FOCUS DILEMMA

A normal lens system has its image plane perpendicular to its optical axis. A probe sitting on a model runway has its optical axis (line of sight) parallel to the ground which of course is the plane of most interest. We can focus a normal lens at any distance along the ground but only one vertical plane will be in sharp focus. Distances on the ground will go out of focus as a function of the depth of focus of the optical system. Although stopping down lenses or using pinhole lenses could provide a large depth of focus at the expense of model lighting and sensor sensitivity problems, resolution must be limited by diffraction effects of the small aperture.

A realistic illustration of the problem might be as follows:

For a 1000:1 scale model, a 20 foot pilot height off the runway would place the probe pupil 6 mm off the model. Let's compare the resolution of "perfect" optical systems of 1 mm and 0.1 mm pupil diameters respectively, viewing a point on the horizon and a point 30° down in the field (35 feet ahead of the pilot). The 1 mm pupil system would resolve 2 arc minutes at the horizon but the poor depth of focus would result in a 6° image smear at the 30° point. The 0.1 mm pupil would reduce this to 36 arc minutes, but due to diffraction limitations, the best resolution anywhere in the field, even at the horizon, would only be 25 minutes. We would also be penalized by a hundred fold loss of brightness compared to the 1 mm system. Trade off choices between the two examples are not very promising either.

TILT FOCUS CORRECTION IN OPTICAL PROBES

Until the employment of the tilt focus correction or "Scheimpflug" technique, it was not possible for a probe to obtain a close approach on the order of 1/4 inch along with a "large" entrance pupil (1 mm) and high resolution (6 arc minutes) over a large field. The parameters appeared to be mutually exclusive.

The tilt-focus or Scheimpflug technique works in the following fashion: The out of focus 6° smear described in the example results from the severe image plane tilt when the probe line of sight is parallel to the object plane which in this case is the ground. This tilted image plane at the probe objective (the equivalent of a small camera lens) varies with the probe's altitude, going from zero tilt to perhaps 45° at touchdown in a typical case. Incidentally, it does not appear practical to place our camera sensor at this variably tilted image plane for a number of reasons including variable field compression, lack of roll capability and dynamic problems. However, a relay lens behind the objective can be used to correct the image tilt by employing the Scheimpflug technique as follows: The tilted image plane is properly relayed to a final fixed normal image plane (at the sensor) when the relay lens is tilted so that a normal plane going through its nodal point joins the intersection of the two image planes in space. In practice, the relay lens is usually a well corrected 1:1 flat field design and will tilt at approximately 1/2 of the image tilt produced at the objective image plane.

PROBES USED IN THE LUNAR MODULE TRAINING PROGRAM

About 6 years ago, the Farrand Optical Co., Inc. designed and built a series of visual simulators for astronaut training as part of the Lunar Module Mission Simulator. Scheimpflug principle probes were employed to obtain a realistic simulation of the lunar landing sequence. Movies taken through this simulator were used during television coverage of the Apollo 15 flight.

The probes had 1 mm entrance pupils and 110° total fields and operated to within 1/2" of a scale lunar model. A 1" vidicon camera system was used to transmit the field to special CRT's and infinity display systems surrounding the LEM cabin. Pitch, roll and yaw capability was incorporated in the probe mechanism. A gantry supplied latitude and longitude motions while the lunar model moved vertically to supply the altitude range.

140° OPTICAL PROBE

a. OPTICAL PRINCIPLES

In 1968 the Air Force Human Resources Lab initiated the development of a new tilt corrected probe which while based on previous experience and principles sought to extend the state-of-the-art in a number of areas. The program involved a study phase and a design and hardware phase which resulted in the engineering feasibility probe model shown in figure 1.

A primary purpose of the program was to achieve a gross increase in the field of view with 140° set as a goal. Close approach and large entrance pupil capability were also considered important in achieving a practical system. The unit was to be designed for later updating in several respects:

1. Hand operation could be updated to servo controlled operation.
2. Relay lenses could be added to provide either:
   (a) multiple outputs for better sensor resolution
   (b) multiple outputs for color TV use
   (c) change format size and mapping characteristics for mating with different sensors and display systems.

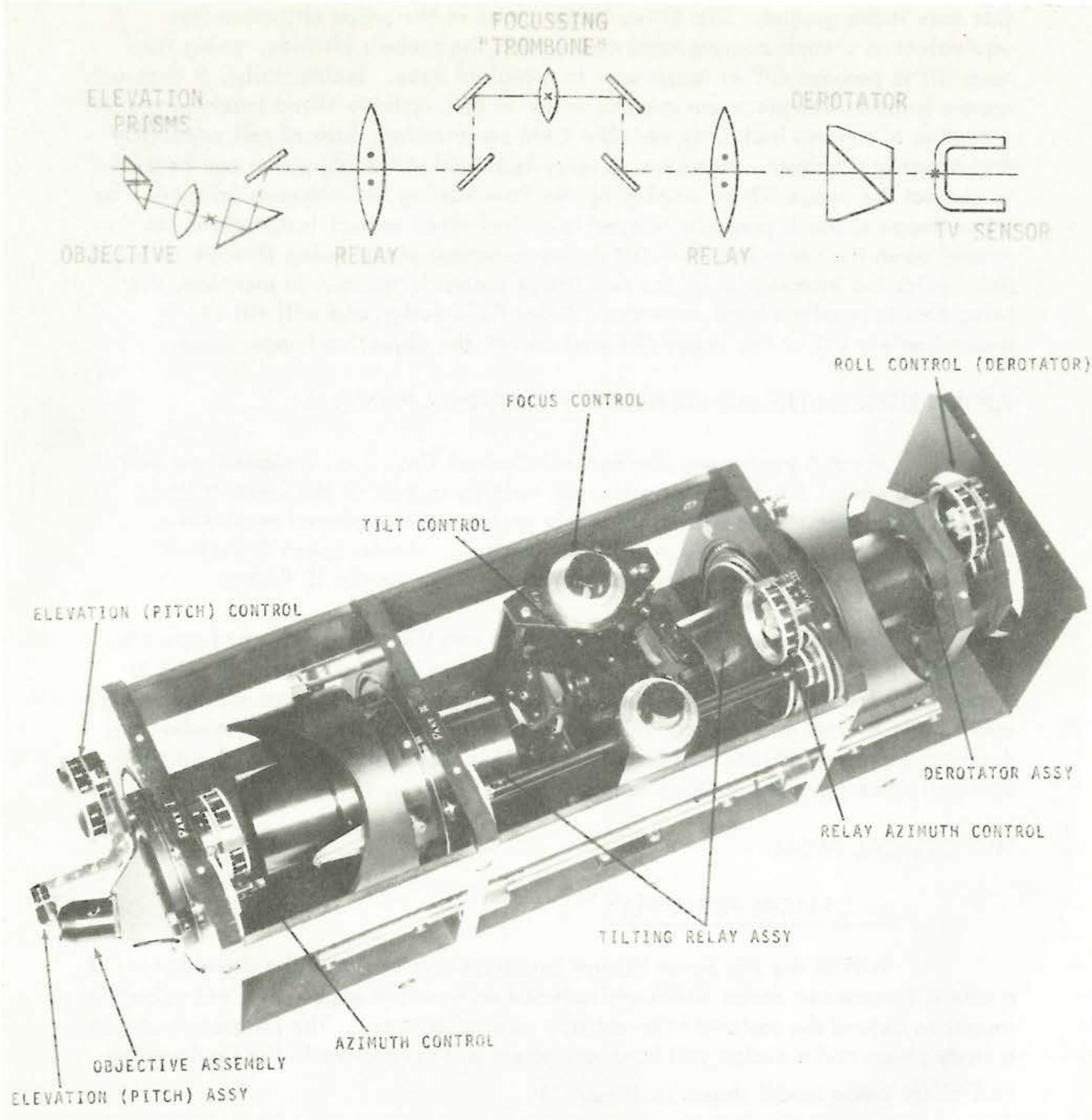

Figure 1. 140^{o} Probe - Engineering Feasibility Model

The engineering feasibility model developed has the following characteristics:

EFL: 6.5 mm
Pupil: 1 mm diameter
FOV: 140^{o} circular
F/no: f/6.5
Mapping: h= Fθ (approximately linear)
Format: 17 mm dia. = 140^{o}
Close approach: 5 mm

Considerable cooperative technical efforts were brought to bear throughout the development. Even in the conceptual stages of the optical design, the mechanical, optical and electrical engineering departments were in close touch so that the resultant device could be made as simple and practical as possible.

In the assembly stages a number of complex alignment instrumentation procedures were employed to achieve the computed design performance in practice.

The model was built and aligned to very close tolerances in order to maximize optical performance and minimize image shifting as a result of component motions. (A lateral image shift of only 4.5 thousandths of an inch could change the line of sight by one degree.) In general, the actual model motion errors were within one thousandth of an inch.

A linear mapping function was chosen because it mates well with a number of infinity display systems and also achieves good illumination uniformity compared to F tan θ mapping which would cause serious losses due to the $\cos^4$ law.

The major optical components of the probe are a 140° field objective lens and a pair of 1:1 tilting relay lenses.

The objective lens is an approximately telecentric design with the external entrance pupil located between the prisms used for pitch control. These prisms are dimensioned to allow a close approach of 5 mm to a model surface.

To maintain the correction levels achieved in the objective at low simulated altitudes, a dual relay system was employed. Each relay operates at 1:1 conjugates and both are tied together mechanically. Field lenses between them serve to image the pupils from one to the other. As each lens tilts to achieve the tilt focus correction, the conjugates increase in length. This increase in optical path is taken up by the focus control which adjusts a trombone arrangement of mirrors. The final image plane is thus fixed in space regardless of the relay tilt. A derotator assembly is located ahead of the final image plane.

b. MECHANICAL IMPLEMENTATION

A number of component motions are employed to allow proper focus operation as well as proper functional operation (pitch, roll and yaw). All controls are hand operated but are designed for updating for servo control.

The assembly containing the objective and scan system has an independent rotation capability and an independent elevation (pitch) prism assembly. Both relay lenses tilt together and also rotate together as an independent assembly. A focus control operates a "trombone" slide mirror arrangement. The derotator assembly also moves independently.

c. FUNCTIONAL OPERATION

(Pitch, roll, yaw, altitude)

Pitch is controlled by the elevation assembly and has a range of +60°, -120° relative to the horizon.

Because pitch motion causes a 1:1 image rotation, the relays must rotate to maintain the correct tilt orientation while the derotator is rotated to keep the image orientation.

Roll is operated independently and is continuous.

Yaw requires the synchronous rotation of the objective, relay and derotator assemblies and is also continuous.

Altitude changes are effected by the relay tilt control and the focus control and vary from ∞ down to 5 mm altitude.

d. MEASURED PERFORMANCE

Resolution tests were made across the field and at the center of the field with relay tilt.

RESOLUTION ACROSS THE FIELD AT INFINITY ALTITUDE

SEMI FIELD ANGLE	ANGULAR RESOLUTION	LINEAR RESOLUTION
0°	3'	200 LP/mm
50°	4'	150 LP/mm
65°	7'	75 LP/mm

RESOLUTION AT THE CENTER OF THE FIELD VS. ALTITUDE

ALTITUDE	ANGULAR RESOLUTION	LINEAR RESOLUTION
∞ -35mm	3'	200 LP/mm
15mm	5'	100 LP/mm
6mm	7'	75 LP/mm

On axis contrast transfer measurements were as follows:

25 LP/mm	80%
50 LP/mm	60%
100 LP/mm	35%
150 LP/mm	20%

The transmission was measured as 35%, therefore the T/no. is approximately 10.5.

e. PHOTOGRAPHIC EVALUATION PROGRAM

More significant perhaps than measured performance is the attempt to demonstrate the usefulness of the techniques developed by direct photography of runway models. A 3:1 magnifying relay was attached to allow the convenience of using a single lens reflex camera body, although this limited the horizontal field of the photos to 96°.

Figure 2 shows the model runway with the probe at the minimum look point of 5 mm. The tilt correction was purposely not applied to illustrate the normal depth of focus problem.

Figure 3 is a similar picture with the tilt correction applied. The smallest pattern shown on the resolution chart sitting on the runway represents 10 minutes of arc per line pair.

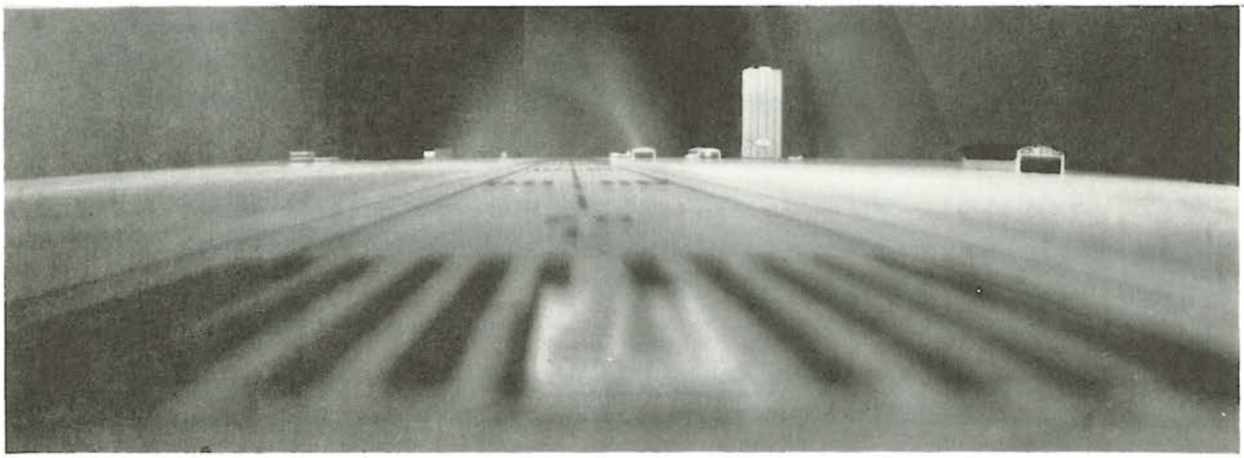

Figure 2. View through Probe Without Tilt Correction

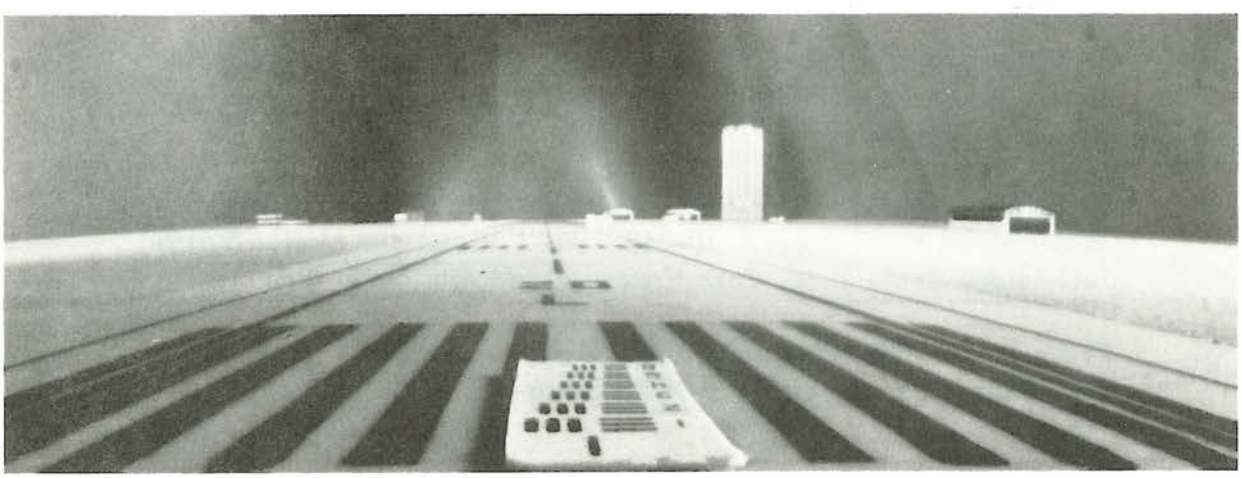

Figure 3. View through Probe Using Tilt Correction

In Figure 4 a penny was placed on the runway to illustrate the scale of the model and the possibilities of a closer approach since the top surface is about .140" from the entrance pupil.

CONCLUSIONS

The realization of this development came about through the concerted effort of a number of individuals and a variety of disciplines. Design goal specifications were chosen effectively for example, so that an advance in the state-of-the-art was realistically possible. Flexibility, as well as close cooperation between the government agency and the contractor also helped immeasurably.

Similarly, optical tolerances in manufacture and assembly were critical in achieving the near diffraction limited optical performance on axis. Individual lens spacers were tailored to measured lens thicknesses and glass index variations.

The engineering feasibility model appears to have enough performance and flexibility to aid in determining where the next significant steps are needed in TV display flight simulators. Will we need even wider fields, closer approaches, more detailed models, more TV sensitivity and resolution, or further advances in optical probes?

Perhaps when the automated version of this probe currently under development is integrated into a complete operating simulation system, the directions for further advances will be clearer.

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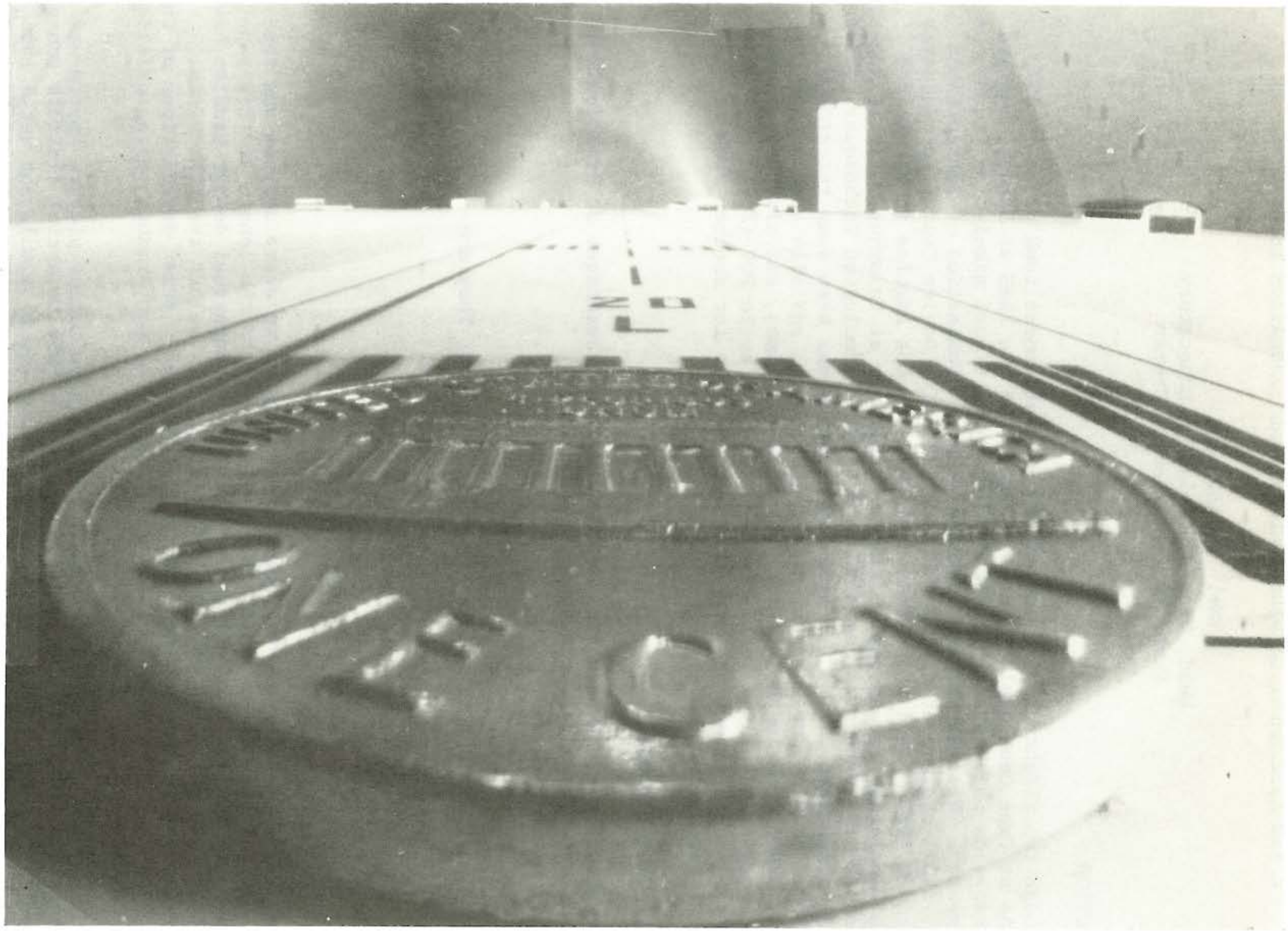

Figure 4. View through Probe of a Penny on Model Runway

A NEW ASSESSMENT OF WIDE-ANGLE VISUAL SIMULATION TECHNIQUES

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Naval Training Device Center

INTRODUCTION

Though two flight simulation techniques conferences took place in 1970 (the AIAA at Cape Canaveral, Florida in March and the RAeS at London, England in October), no objective appraisal of wide-angle visual simulation techniques was presented. William Ebeling provided a brief examination of narrow field of view visual systems at the Second Naval Training Device Center and Industry Conferece in 1967[1] and at an AIAA Conference in Los Angeles in March 1968[2]. The AIAA Simulation for Aerospace Flight Conference at Columbus, Ohio in August 1963 produced two extensive assessments of Visual Simulation Techniques, which are still referenced [3], [4]. Since 1963, there has been some research accomplished on wide-angle visual system components, and also acquisition of operating experience in the military services, airlines, and aircraft manufacturing companies with 1962 state-of-the-art narrow angle FOV (Field of View) visual systems. It therefore appears to be the time for another look at the stable of systems available.

STATEMENT OF THE PROBLEM

The question to be answered is: What are the advantages or disadvantages of the various systems and components available now?

ANALYSIS

What are the possible wide-angle visual systems? They are:

1. Motion Pictures
2. CCTV with Physical Image Generation
3. CCTV with Computer-Generated Images
4. Optical Display Projection
5. Hybrid

Only some research and development accomplished on above systems and components since 1962 will be described, due to limits on the length of this paper. In addition to the hardware effort, at least four conceptual design studies have been, or will be published shortly, which attempt to select the best visual system for specific applications, will be considered. Brief descriptions of the systems and components will be first given and then, performance characteristics will be discussed.

1. MOTION PICTURE SYSTEMS. While a wide-angle motion picture system was developed by NAVTRADEVCEN in 1952, and applied in 1956 to aerial flexible gunnery training[5], this approach was not considered for visual simulation until 1966[6]. The latter wide-angle motion picture system consists of a Fairchild 160^{o}H x 60^{o}V projector lens, a Century projector with a 2500 W Xenon illuminator, fast film pulldown and a 12-1/2' radius high gain spherical screen. Seventy millimeter film taken with a Fairchild wide-angle f/4 camera lens on a Mitchell camera provided the image storage. The projector had a continuous film speed range of 4 to 1. The initial application was to supplement target acquisition field test data by means of laboratory simulation of the pilot's visual task.

Preliminary evaluation of this system by NAVTRADEVCEN for training was conducted in June 1970 using Boeing's version of the JTF-2/SANDIA CORPORATION simulation facility, described in reference [7]. In the meantime, UCLA has also used another version for highway driving research.

2. CCTV (CLOSED CIRCUIT TELEVISION) WITH PHYSICAL IMAGE GENERATION. These systems can be described as the 3-D/2-D model with TV camera or FSS (Flying Spot Scanner) pickups and Real or Virtual Image Display. Some of the new components developed are:

a. TV camera with pinhole lens and low light level camera tube for wide-angle and great depth of field.[15, 17]

b. Matched wide-angle anamorphic lenses for a single channel TV system using a TV camera and an Eidophor Light Valve Projector.[16]

c. Wide-angle articulated optical probe with Scheimpflug correction.

d. In line infinity display system (Farrand pancake window).[23]

e. Light weight reflective infinity display system.[20]

3. CCTV WITH COMPUTER-GENERATED IMAGES. These systems replace the physical model of the real-world with a mathematical model and logic stored in a computer (mostly digital). The display portion is as before. The image can be a line drawing with no shading, or a TV raster with computer modulated video in monochrome or color. Both approaches have been developed since 1962[27,28], and with the TV raster approach in use for space flight research.

4. OPTICAL DISPLAY PROJECTION. Both diascopic projection (transparency), and epidiascopic (solid models) techniques have been examined during this period. An improved version of the point light source projection system has been assembled at NAVTRADEVCEN for application to fixed wing aircraft landing, cross-country flight, and also for ship handling in a harbor. An epidiascopic system was developed by Dalto for the FAA Academy at Oklahoma City for Control Tower Operator Training and projected three narrow FOV images of solid aircraft models on a circular screen around a control tower mockup. The images were superimposed on slide projection backgrounds of the airport surroundings. More on the first scheme later.

5. HYBRID. An example of a hybrid system is the Differential Maneuvering Simulator at NASA, Langley Research Center. Here a narrow field of view image generated by a 3-D model and TV camera is projected through a gimballed mirror onto a sphere and optically mixed with a low detail wide field of view background image generated by a point light source. Details and uses are contained in reference(22).

With this brief listing of some research on wide-angle visual simulation components completed, an examination of some of the components' or systems' performance is in order.

RESULTS

To better see the relationship of all the components in a visual simulation system, an improved version of my block diagram is presented, figure 1. We will review only the blocks: Image Storage, Image Generation, Display Unit, and