Summarizing the advantages of the system are:

a. Highlight output
b. High potential resolution
c. High contrast ratio.

With the improved cameras, the light valve system will be equal to the CRT system in visual acuity, with highlight brightness increasing by a factor of ten, and vertical resolution improved by 40%.

The criterion of acceptable illumination vs resolution, or visual acuity, has been studied many times in the past. The studies have generally concluded that improvements in tasks result quite rapidly from one FC to 10 FC illumination. The rate of increase, however, reduces sharply above this value. The level of 10 FTL should be acceptable in the developed system.

Other Light Valve Systems. Two other light valve systems are in development, or production, which offer real solutions to wide-angle displays, and should be mentioned here for comparison to the in-house system.

a. The color TV projector, a light valve by General Electric uses a single gun to write three color pictures simultaneously on the same control layer in the form of diffraction gratings. Where the pitch of the diffraction grating determines the dispersion of the spectra, while the amplitude determines the intensity. The resulting optical spectra are filtered at the output bar plane to give the desired colors. The performance of the system currently in-house is defined as follows:

Brightness, 650 W Xenon	
Intensity (10 FTL on SG-2.5 @ 7' x 10' screen)	300 Lumens
Resolution	600 lines
Contrast Ratio	75:1
Screen Width	2'-20'

The reliability of the system is reported to be 1500 hours, with further development expected, to provide operating life time of greater than 5000 hours, without replacement of the sealed unit. This light valve has been tested satisfactorily at the maximum motion of 3.7g on the American Airlines 707 Flight Simulator at Dallas.

The projector has recently been redesigned to improve the optical efficiency. It is now claimed that a 500W lamp is equivalent to a 2Kw in another system. With 27 optical surfaces, improvements have been made in the dichroic transmission of the surfaces. The advantages of the system are: the relative portability with the remote projection head; full color, and low power requirements. Also, no registration problems exist with a single electron gun. The sealed unit eliminates heater contamination from the control layer. The disadvantage of the system is the replacement cost of the sealed unit - reported at $10,000.

b. The third light valve, which should be mentioned, reported at the SID Conference in March 1971, is the Japanese version of a sealed light valve, which again is unique in the method of intensity modulation of the target. The target consists of a transparent resistive membrane with a mesh electrode and deformable fluid. An IO glass target is used as the resistive membrane. To this, a vacuum deposted Al film is applied. A thin silicon oil film is applied to the surface of the membrane. An electron beam scans the other side of the target and sets up an electric charge causing deformation of the oil film. With this system, the oil film is not scanned directly, so replenishment or a vacuum pump are not required.

The results of this system, obtained to date:

Light intensity	
500W Xenon	100 Lumens
Resolution	300 lines
Contrast Ratio	15-25:1

Further improvements in brightness and resolution remain to be achieved.

APPLICATIONS

Wide-angle projection television can be used, where a large FOV is required, in particular training situations. To mention, and discuss several of these:

a. Experimental Destroyer Docking Simulator. The Simulator located at the Center utilizes the three CRT projectors, described earlier. A computer-controlled gantry probes a 100:1, 3D model, with the optical probe mentioned earlier, to provide the video for three channels. A trainee viewing the display provides engine and rudder orders to control the vessel. The verbal orders are fed to the computer, where the recomputed, math model equations provide the signals to update and control the gantry's azimuth and heading. The visual system was evaluated[8] subjectively by Naval officers assigned to destroyer duty. The system, generally rated favorable, was critized for resolution of detail of the visual system. The relatively poor resolving power and highlight brightness were the causes.

b. Carrier Landing Flight Trainer. Device 2H87 was designed with a virtual image 240° FOV television display.

c. OOD Trainer[9]. This simulator, the first to use the light valve wide-angle anamorphic lens is a research tool to study visual systems, in particular, wide-angle projection television and its application for underway officer of the deck trainee and,in particular, a replenishment at sea operation, using only visual references. This operation involves approaching and keeping alongside another ship for a long time and under extremely adverse weather conditions. Range data varies from 1000 yards, at the start of the problem, to about 30 yards at the conclusion.

The use of the wide-angle anamorphic lenses provided an interesting problem. With the high geometric distortion, an image generated in the pickup lens must be displayed in exactly the same position in the field of view of the projection lens, or the distortion introduced in the image will not rigorously cancel. This dictated that no electronic changes in the image could be made, such as ranging or changes in azimuth or elevation. As such, the changes must be performed mechanically. The 3D model and camera will be servo driven.

CONCLUSIONS

In conclusion, the current projection system may be summarized as follows:

	Resolution
Camera Lens	2000 TV lines
Pickup Tube	1500 " "
Video Amp (40 mhz)	1500 " "
Light Valve Projector	1600 " "
Projection Lens	1700 " "
System Resolution	730 " "
With a Highlight Brightness	10 FTL
on a Field of View of	60^o x 160^o

<u>References</u>

1. Altes, S.K. and Chu, J.H.: Feasibility Study, Wide-Angle Television Display, General Electric Company, November 14, 1956.

2. Collier, A.D. et al, Study of Advanced Vehicle Simulation Techniques, Technical Report: NAVTRADEVCEN 70-C-0312-1, Final Report, April 1971.

3. Kashork, E.F.: A Wide-Angle TV Camera Pickup Lens System Using Reflective Optics, Technical Report: NAVTRADEVCEN IH-186, August 1970.

4. Field Jr., J.M.: Technical Description of the Douglas MSSD Earth Surveillance and Rendezvous Simulator, Douglas Missile and Space Systems Division, March 1967.

5. Memo of 51:FJO of 16 Dec 1970 to Code 53; Subj: 60^o x 60^o Anamorphic Projection Lens; evaluation of

6. Good, W.E., and True, T.T.: Performance Characteristics of the New Single Gun Light Valve Color TV Video Projector, IEEE Convention Paper, New York City, March 1970.

7. General Electric Company "Color System Specifications Condensed", April 15, 1971.

8. Chea, F.: Interim Report, NAVTRADEVCEN, Subjective Validation of Experimental Destroyer Docking System, May 1971.

9. Kashork, E.F.: Technical Report: NAVTRADEVCEN IH-197, Design Analysis Report, OOD Simulation.

COMPUTERIZED OPERATIONAL TRAINING FOR AEROSPACE SYSTEMS: AUTOMATED PROGRAMED INSTRUCTION (API)

MR. R. T. MURRAY
Air Operations Division, System Development Corporation

This paper concerns the Automated Programmed Instruction project developed and produced for the United States Air Force Aerospace Defense Command by the System Development Corporation. In 1965, the System Development Corporation commenced a project to determine the feasibility of implementing the concept of computer-assisted instruction into an operational air defense computer. This early research was conducted on the BUIC Air Defense System computer. BUIC, an acronym for Backup Intercept Control System, was then in the BUIC II phase. This early SDC research culminated in a determination that the concept of computer-assisted instruction could effectively be implemented into an operational system. In essence, the determination that individualized training based on accepted concepts of computer-assisted instruction could be accomplished, using a military air defense operational computer, as the teaching medium.

Following this feasibility study, the Aerospace Defense Command requested that SDC undertake a project to implement this type of training into the BUIC III advanced air defense system. The Air Force termed this training concept Automated Programmed Instruction, or API. The reason for using the term API rather than the acronym CAI which stands for Computer-Assisted Instruction was that API was totally based on the teaching concepts of programmed instruction, as developed during the 1950's. The SDC Automated Programmed Instruction training vehicle therefore was an application of proven training concepts and advanced computer technology. In API training the computer presents instructional information to the student, quizzes him as to how well he learned the information, presents an immediate feedback as to the correctness of his response, and when he makes an error, provides remedial instructions.

API commenced to be integrated into the BUIC III operational air defense system in 1969. For the next year it was available for use at selected BUIC III operational defense control centers throughout the United States. Before it was fully implemented, however, API was dropped from the BUIC III Operation System due to budgetary and personnel cutbacks in the command. Nevertheless, SDC's preliminary validation tests of API proved it to be an outstandingly effective training tool. Air Force personnel were enthusiastic about this form of training, and validation tests results affirmed criterion tests were met.

API was designed for integration into the system on the basis of several operational criteria. First and foremost, the Air Force specified that API was to run concurrent with live air operations. In other words, live air defense was to be conducted simultaneous with the conduct of API at the BUIC III center. Each BUIC control center has ten consoles, one of which could be placed in the API training format, while the remaining nine were used to conduct live air defense. The API data was thus never mixed with the live data being processed in the center.

Of course the live system had precedence over API training at all times. An example of this is that in the event an emergency occurred in the live system or, when the BUIC control center received an excessive amount of live radar returns, in these and like instances API was terminated and removed from the system automatically and instantaneously. The console assigned to API training was also instantaneously returned to normal live operations.

API, therefore, was gainfully employed concurrent with the center's live air control responsibility but without interfering or impinging on the operational requirements of the BUIC system. Even though only one console was used for API training at each center, approximately 12 hours of each day could be used for API training purposes at each location.

Another functional criteria in the development of API and certainly one of the most advantageous features from a cost-effectiveness viewpoint was that API used existing air defense computer programs. It used the existing tracking program, the existing display program, and the existing tactical weapons program. API, from a computer programming viewpoint, was relatively simple to develop, making maximum use of the existing operational system. The API concept was, therefore, basically cost-effective to develop calling for a relatively small amount of original computer programming. Also, by using the operation computer programs to process the training data, very realistic training situations were achieved. The simulated interceptor was guided to its target in an API training situation exactly as if it was an interceptor on time-division data link, because the operational computer program processed the API data the same way that it processed live data.

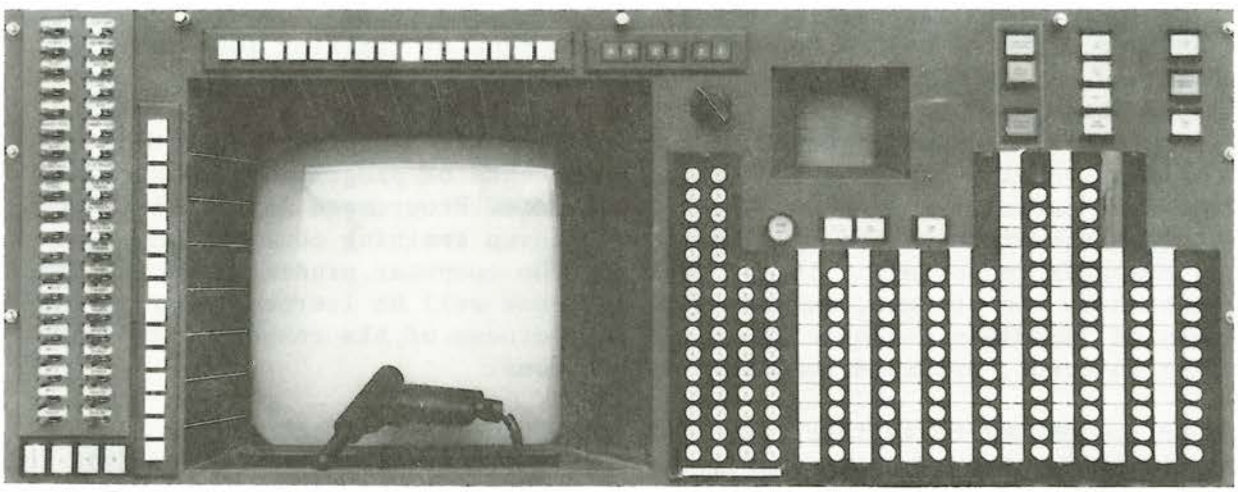


Figure 1. BUIC III Console Picture

Another obvious advantage of the API concept was that it used the same operator console as used in live air defense (see figure 1). The trainee used the identical switch actions and the identical light sensor actions as he did to conduct live air defense. The trainee did not, therefore, have to learn to manipulate a unique teaching machine to be able to take API training. The console was used to train the operator to take the same actions, interpret the same alpha numeric data presented on the situation display or SID and make the same decisions as called for in his particular operational position.

In using the operational Air Defense Program or ADP (see API System Flow Chart), which runs on a real-time basis, prevision was made to "freeze" the API air picture for an indefinite length of time allowing the trainee to self-pace his own response to the training objective being presented. (See figure 2.)

Generation of API course material was also done from existing computer programs. In this case API courses were produced using the BUIC Exercise Preparation System or BEPS. With minor modification to the BEPS program, eight different API courses were generated at SDC's Santa Monica facility accounting for approximately 24 hours of concentrated site specific training materials. In addition to modifying BEPS and ADP the BUIC Operational Recording Tape (BORT) and the BUIC Analysis Reduction System (BARS) were also slightly modified to accept, record and printout data concerning student progress, errors, time latencies, and box scores.

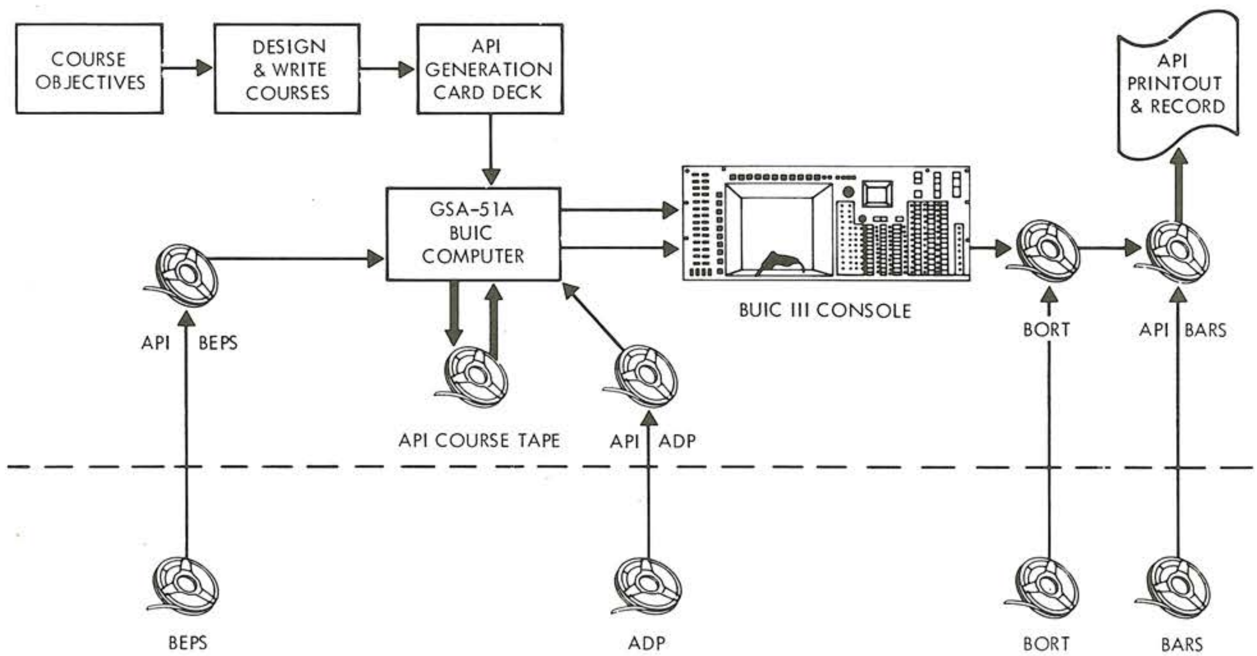


Figure 2. API System Flow Diagram

Each course was stored on an individual computer tape. The courses were broken into 15 to 30-minute lessons so the student would have logical break points, thereby, avoiding long attention-span problems. Because of the self-pacing feature of API, a trainee working at an API console could stop his API training lesson at any point to accomplish other tasks, such as answering a phone, and then return to the console, take a continue action and without further adieu go right on through the training program.

All courses were based on a 3-part mixture. First, basic instructional information was presented to the trainee. Secondly, the trainee was asked to take operational switch actions identical to those found in live air and third, the trainee was presented multiple choice questions. The method of presenting this information was done on an individualized basis with regard to the position being trained.

A Weapons Director trainee was taught weapons direction, an Air Surveillance Operator was taught air surveillance operations, and so on. Remedial training loops were built into each course as determined necessary by field trials conducted by the course designer. If a trainee made a critical error, while going through an API course, remedial training was automatically given to clarify the point being taught and to help assure that the trainee would benefit from the rest of the course.

Now that the basic objectives and methods of operation of automated programmed instruction have been presented, let's take a look at it from the viewpoint of the trainee.

The BUIC III console is a rather complex piece of equipment to master. The SID picture shown here (see figure 3) is taken from the Weapons Director Course and is providing the trainee information regarding the Selective Identification Feature (SIF) number switch action. This example is taken from the Cape Code environment where BUIC III site Z10 is situated. Once the trainee has read this information he will take the "continue" action which is a single button switch action. The continue action will force the API course into the next frame of instruction. The English text that is displayed on the scope is unique to API. The operational display does not have English textual information on it.

Following the reading of this information the trainee will continue on to the next frame of instruction.

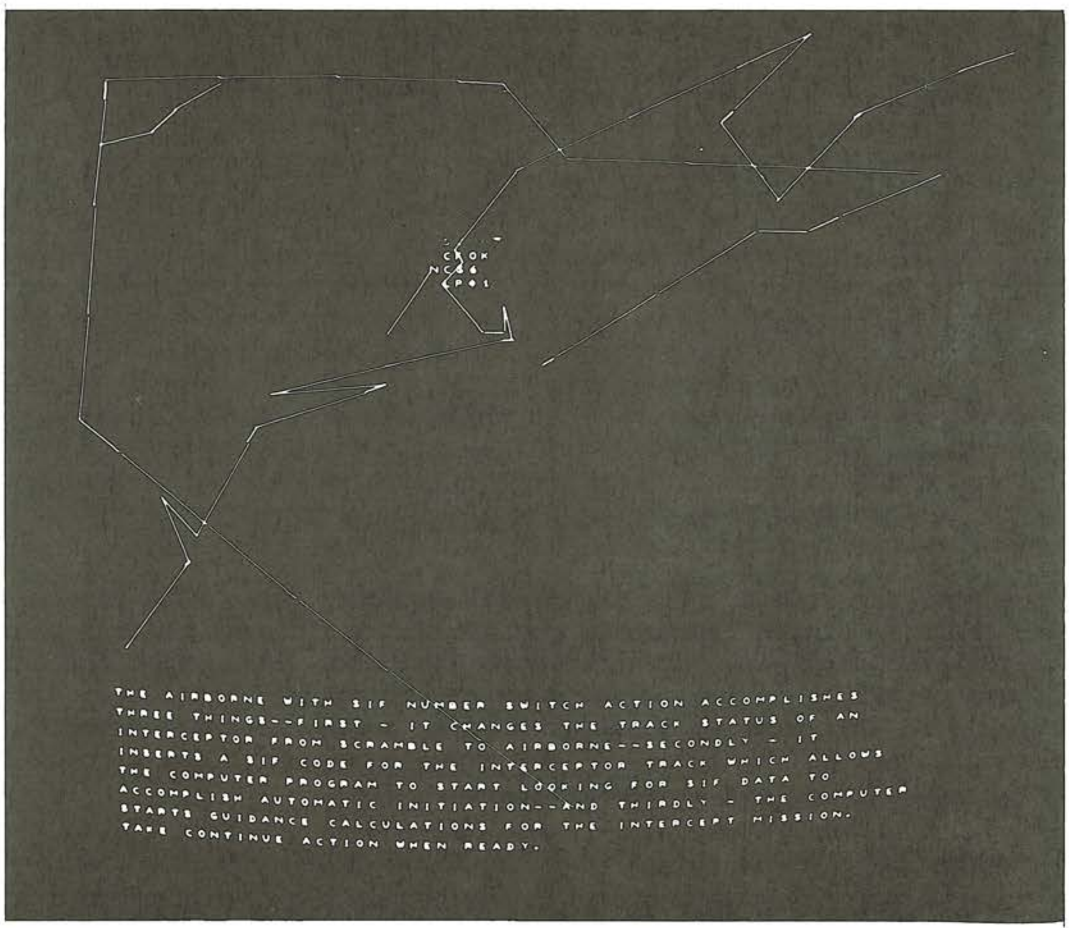


Figure 3. BUIC III SID Picture - Text Display

In this case (see figure 4), the next frame of instruction is a multiple choice question based on the information just provided to the trainee. Once the trainee has read the question and selected the answer he thinks is most appropriate he will light sensor the dot to the left of that answer.

Once he has light sensored his answer he will be provided with feedback as shown here at the top of the scope indicating whether he was right or wrong and informing him to continue on in the course.

In this case the trainee answered correctly and he is informed that the system will now explain how the action is taken.

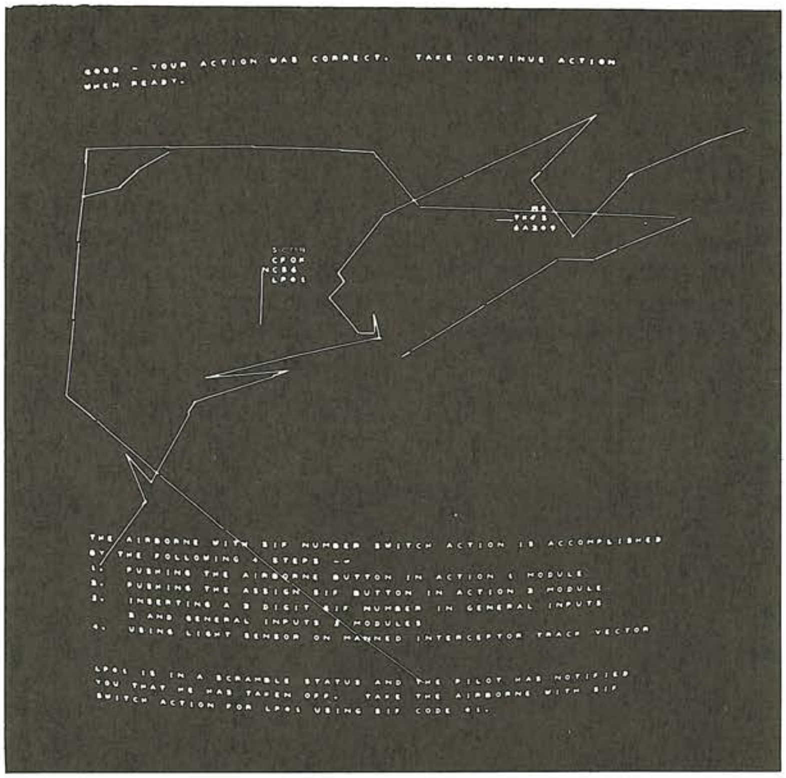


Figure 4. BUIC III SID Picture - Multiple Choice Display

The airborne with SIF number switch action is accomplished by several steps. These steps are pointed out on the scope (see figure 5), the trainee will take his time to read these instructions then insert into the console keyboard the proper button actions which constitute the operational action.

Lima Papa 01 is the interceptor he is working with in the center of the scope. The airborne with SIF number switch action combines the keyboard and the light sensor action. Here the trainee has just light sensored the track. He has received feedback telling him once again good, he took the proper action. When the trainee takes the proper action the aircraft symbology goes airborne, exactly as it would in live operations. After taking the continue action the next frame of instruction asks the trainee to take this same action on a new interceptor without the cues present. He will do this purely by recall to reinforce the training he just received. If he fails to remember the proper actions, he will be recycled to the previous frame which contained the cues.

Following this sequence the trainee is once again provided information of a textual nature.

The eight API courses produced by SDC covered the areas of weapons direction, air surveillance, passive tracking, radar input countermeasures, and identification. Weapons, air surveillance and passive tracking each had elementary lessons for newly assigned personnel and advanced lessons built to stress experienced personnel who were classified as operational ready. The countermeasures and identification courses were both elementary courses.

The API concept of using operational computers, programs and data bases is still new in the world of training. Most computer based systems are designed for workloads which are seldom reached. The BUIC III system as an example is designed to combat a massive air attack. During daily operations the computer is no where near being saturated in its workload. API took advantage of this fact and therefore extended the usefulness of the computer system while simultaneously assisting on-site training personnel in their task of ensuring effective operational status among all crew members.

Due to its individualized approach, API proved to be a very powerful training tool. Unlike a lecture, a movie, or a text book API forced the trainee to physically respond to instruction and immediately informed him of the correctness of his response. Only after the trainee has completed the lesson does he receive a box score on his SID and an off-line hardcopy printout of his performance in the course. This automatic printout was proof of the trainee having taken the course and proved useful to the on-site training officer in determining future training assignments.

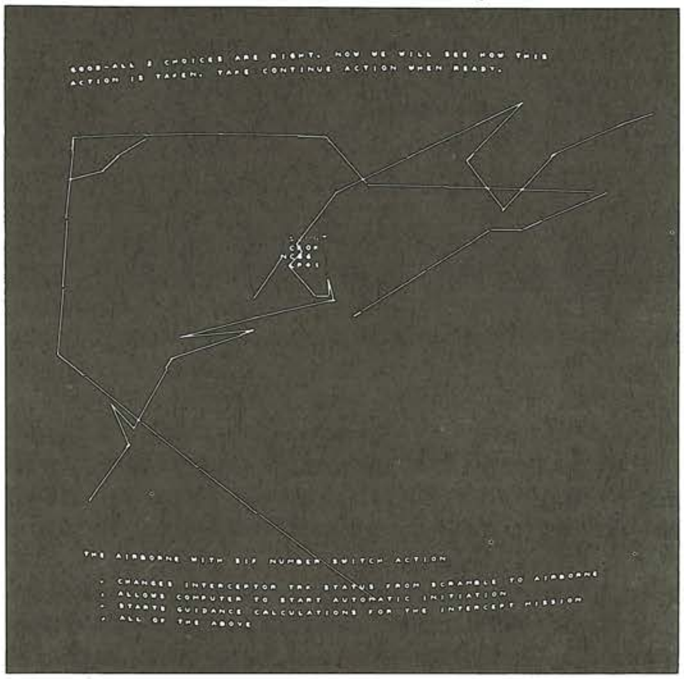


Figure 5. BUIC III SID Picture - Operational Action Display

The courses were system engineered to the point of teaching only those subjects which were critical to effective and efficient operator performance. No frills or attempts to use the computer as a replacement for a text book were included in our training course development. Because of this fact, and the subsequent direct carry over to live operations of the skills taught, all Air Force trainees exposed to SDC's validation runs of API expressed enthusiasm for this unique form of training. It's application to other operational settings seems evident.

A PRINTER PLOTTER PROGRAM FOR DIGITAL SIMULATION STUDIES

MESSRS. K. L. PRIME AND C. S. BAUER
Department of Industrial Engineering and Management Systems
Florida Technological University
Orlando, Florida

Many computer simulation experiments involve the generation of large quantities of output data, resulting in extensive tables of numerical information. These tables are often difficult to interpret without considerable effort on the part of the reader, particularly with respect to the detection of variable trend perturbations in long strings of data. To alleviate this difficulty, a computer subroutine was developed to provide immediate printer plots of data arrays generated in simulation program runs. These plots allow the immediate examination of experimental run results, and provide the user with an easy-to-read tool for determining requirements for additional computer runs.

The program will plot up to five simultaneous data curves, with automatic plot variable scaling on each curve to achieve maximum output resolution in each instance. If the user wishes to plot any number of curves less than the five maximum allowed on a given set of axes, it is only necessary to fill the unused arrays appearing in the call statement with some common constant value, and the curve for this array or group of arrays will not be plotted. Similarly, simulation program outputs with more than five variables can easily be accommodated with multiple calls to the plotting program.

The plot routine was written in IBM 1130 FORTRAN, but should be acceptable to any FORTRAN compiler with an alphanumeric capability and provisions for a DATA statement. In fact, the authors use the same program deck on both IBM 1130 and IBM 360/65 computer runs, with the only change required being the appropriate selection for the FORTRAN logical unit number for the output printer. A complete listing of the program appears in figure 1.

The plotter is called from the data generation program with a statement of the following form:

CALL YPLOT(NPTS, A, B, C, D, E, X, IFLAG)

where: NPTS = scaler integer variable giving the number of points to be plotted. The subroutine presently uses variable dimension array allocation to conserve memory requirements, and the reader should be aware that this feature may cause difficulties in other FORTRAN implementations.

A, B, C, D, E, = one dimensional FORTRAN arrays of length 'NPTS' containing the data points to be plotted.

X = one dimensional FORTRAN array of length 'NPTS' containing the values of the common independent variable values for each of the five data curves.

```
FORTRAN IV G LEVEL  19                YPLOT              DATE = 71177          14/34/24              PAGE 0001

0001              SUBROUTINE YPLOT  (M,AA,BB,CC,DD,EE,ZZ,KK)
0002              DIMENSION  X(100)
0003              DIMENSION  AA(2),BB(2),CC(2),DD(2),EE(2),ZZ(2)
0004              DATA  BL,A,B,C,D,E,DOT,DASH/' ','A','B','C','D','E','I','-'/
            C     FOLLOWING CARD SETS FORTRAN LOGICAL UNIT NUMBER FOR PRINTER...
0005              J = 6
0006              AMIN = AA(1)
0007              AMAX = AA(1)
0008              BMIN = BB(1)
0009              BMAX = BB(1)
0010              CMIN = CC(1)
0011              CMAX = CC(1)
0012              DMIN = DD(1)
0013              DMAX = DD(1)
0014              EMIN = EE(1)
0015              EMAX = EE(1)
0016              DO 555 N=1,100
0017          555 X(N) = BL
0018              DO 35 I=1,M
0019              IF ( AA(I) - AMAX) 10,11,11
0020           11 AMAX = AA(I)
0021           10 IF (AA(I) - AMIN) 12,12,13
0022           12 AMIN = AA(I)
0023           13 IF (BB(I) - BMAX) 20,21,21
0024           21 BMAX = BB(I)
0025           20 IF (BB(I) - BMIN) 22,22,23
0026           22 BMIN = BB(I)
0027           23 IF (CC(I) - CMAX) 24,25,25
0028           25 CMAX = CC(I)
0029           24 IF (CC(I) - CMIN) 26,26,27
0030           26 CMIN = CC(I)
0031           27 IF ( DD(I) - DMAX) 28,29,29
0032           29 DMAX = DD(I)
0033           28 IF (DD(I) - DMIN) 30,30,31
0034           30 DMIN = DD(I)
0035           31 IF (EE(I) - EMAX) 32,33,33
0036           33 EMAX = EE(I)
0037           32 IF (EE(I) - EMIN) 34,34,35
0038           34 EMIN = EE(I)
0039           35 CONTINUE
0040              AWID = AMAX - AMIN
0041              BWID = BMAX - BMIN
0042              CWID = CMAX - CMIN
0043              DWID = DMAX - DMIN
0044              EWID = EMAX - EMIN
0045              AUNIT = AWID / 100.
0046              BUNIT = BWID / 100.
0047              CUNIT = CWID / 100.
0048              DUNIT = DWID / 100.
0049              EUNIT = EWID / 100.
0050              AMID = AWID / 2. + AMIN
0051              BMID = BWID / 2. + BMIN
0052              CMID = CWID / 2. + CMIN
0053              DMID = DWID / 2. + DMIN
```

Figure 1. Plotter Program Listing (1 of 3)

```
FORTRAN IV G LEVEL  19                YPLOT              DATE = 71177          14/34/24              PAGE 0002

0054              EMID = EWID / 2. + EMIN
0055              NK = 1
0056              DO 1000  L = 1,M
0057              Z = L
0058              IF ((L/10) - (Z/10.))  40,41,40
0059           41 DO 223  LL = 1,100
0060          223 X(LL) = DASH
0061           40 X(1)  =DOT
0062              X(25)  = DOT
0063              X(50) = DOT
0064              X(75) = DOT
0065              X(100)= DOT
0066              IF (AUNIT) 90,93,90
0067           90 KA = (AA(L) - AMIN) / AUNIT
0068              IF (KA)  91,91,92
0069           91 KA = 1
0070           92 X(KA) = A
0071           93 IF (BUNIT) 94,97,94
0072           94 KB = (BB(L) - BMIN) / BUNIT
0073              IF (KB) 95,95,96
0074           95 KB = 1
0075           96 X(KB) = B
0076           97 IF (CUNIT) 98,101,98
0077           98 KC = (CC(L) - CMIN) / CUNIT
0078              IF (KC)    99,99,100
0079           99 KC = 1
0080          100 X(KC) = C
0081          101 IF (DUNIT) 102,105,102
0082          102 KD = (DD(L) - DMIN) / DUNIT
0083              IF (KD) 103,103,104
0084          103 KD = 1
0085          104 X(KD) = D
0086          105 IF (EUNIT)106,109,106
0087          106 KE = (EE(L) - EMIN) / EUNIT
0088              IF (KE) 107,107,108
0089          107 KE = 1
0090          108 X(KE) = E
0091          109 IF (NK - 1)  151,152,151
0092          152 WRITE (J,111) AUNIT, BUNIT, CUNIT,DUNIT,EUNIT,
                 1  AMIN, AMID, AMAX,
                 2 BMIN, BMID, BMAX,
                 3  CMIN, CMID, CMAX,
                 4 DMIN, DMID, DMAX,
                 5 EMIN, EMID, EMAX
0093          111 FORMAT('1'    ,'EACH UNIT ON THE Y -AXIS  =  ' ,
                 1  F10.5,'  FOR EQ. A  ,   ',3X,F10.5,'  FOR EQ. B  ,  ',3X,
                 1  F10.5,'  FOR EQ. C  ,   ',3X,/,T31,F10.5,'  FOR EQ. D  ,  ',3X,
                 1  F10.5,'  FOR EQ. E ',
                 25(/,F15.5,T45,F20.5,T95,F20.5),
                 3/,T10,'+',T59,'+',T109,'+',/,T10,100('-'))
0094          151  IF  (KK)  155 , 156 , 155
0095          156 WRITE  (J,116) L,(X(MM),MM=1,100)
0096          116 FORMAT (1X, T6, 14, 100A1)
0097              GO TO  77
```

Figure 1. Plotter Program Listing (2 of 3)

```
  155 WRITE(J,117)  ZZ(L),(X(MM),MM=1,100)
  117 FORMAT (1X, F8.2,100A1)
   77 IF ((L/10) - (Z/10.))  45,46,45
   46 DO 47  KL = 1,100
   47 X(KL) = BL
   45 IF(NK - 50)  153,154,154
  154 NK = 0
  153 NK = NK + 1
      IF (AUNIT)    400,401,400
  400 X(KA) = BL
  401 IF (BUNIT)    402,403,402
  402 X(KB) = BL
  403 IF (CUNIT)    404,405,404
  404 X(KC) = BL
  405 IF (DUNIT)    406,407,406
  406 X(KD) = BL
  407 IF (EUNIT)    408,1000,408
  408 X(KE) = BL
 1000 CONTINUE
      RETURN
      END
```

Figure 1. Plotter Program Listing (3 of 3)

```
EACH UNIT ON THE Y -AXIS  =     0.85410  FOR EQ. A  ,       0.65424  FOR EQ. B  ,       0.20000  FOR EQ. C  ,
                                0.25631  FOR EQ. D  ,       0.0      FOR EQ. E
 314.59009                                  357.29492                                      400.00000
 200.00000                                  232.71179                                      265.42358
 100.00000                                  109.99994                                      119.99989
 100.00000                                  112.81557                                      125.63115
 120.00000                                  120.00000                                      120.00000
   +                                                +                                                 +
   ----------------------------------------------------------------------------------------------------
  1D                       I                        I                        I                        A
  2D         B             I                        I            C           IA                       I
  3I     D                 I       B                I   A                    I          C             I
  4I                D      I        A               I     B                  I                   C    I
  5I                A      I       D                I                        B                      C I
  6I     A                 I                       DI                        I             B         CI
  7A                       I                        I              D         I                     B CI
  8A                       I                        I                        I  D                    CB
  9A                       I                        I                        I             D       B CI
 10I----A------------------I------------------------I------------------------I---------------B----D--CI
 11I          A            I                        I                        I       B               DI
 12I                 A     I                        I                       BI                       CD
 13I                       A                        I               B        I                     D CI
 14I                       I    A                   I        B               I                 D     CI
 15I                       I        A               I   B                    I             D          C
 16I                       I           A            B                        I        D               C
 17I                       I            A          BI                        I   D                    C
 18I                       I            A          BI                        ID                       C
 19I                       I           A            B                      D I                        C
 20I-----------------------I---------A--------------I--B-----------------D---I------------------------C
 21I                       I       A                I    B               D   I                        C
 22I                       I     A                  I       B            D   I                        C
 23I                       I    A                   I         B           D  I                        C
 24I                       I  A                     I           B          D I                        C
 25I                       I A                      I            B           D                        C
 26I                       I A                      I             B          ID                       C
 27I                       IA                       I             B          I  D                     C
 28I                       I A                      I             B          I   D                    C
 29I                       I A                      I            B           I   D                    C
 30I-----------------------I--A---------------------I------------B-----------I----D-------------------C
 31I                       I  A                     I           B            I    D                   C
 32I                       I   A                    I          B             I   D                    C
 33I                       I   A                    I          B             I   D                    C
 34I                       I    A                   I         B              I   D                    C
 35I                       I    A                   I         B              I  D                     C
 36I                       I    A                   I         B              I  D                     C
 37I                       I    A                   I         B              I D                      C
 38I                       I    A                   I         B              I D                      C
 39I                       I    A                   I         B              I D                      C
 40I-----------------------I----A-------------------I---------B--------------I-D----------------------C
 41I                       I   A                    I         B              I D                      C
 42I                       I   A                    I          B             I D                      C
 43I                       I   A                    I          B             I D                      C
 44I                       I   A                    I          B             I D                      C
 45I                       I   A                    I          B             I D                      C
 46I                       I   A                    I          B             I  D                     C
 47I                       I   A                    I          B             I  D                     C
 48I                       I   A                    I          B             I  D                     C
 49I                       I   A                    I          B             I  D                     C
 50I-----------------------I---A--------------------I----------B-------------I--D---------------------C
```

Figure 2. Plotter Output for Simulation Example

IFLAG = scaler integer control variable. If set equal to zero, the program will ignore the values in the X array and print an integer count of the data point numbers at the left of each row of the output plot. If set equal to one, the program will print the appropriate values from the X array at the left of each row of the output plot.

To illustrate the use of the program in a representative simulation study, consider the simple production-inventory system described in (1). The model equations are given in the reference in the DYNAMO Computer Language format, but may easily be converted to a state-variable differential equation following the procedure outlined in (2). Assuming a state vector definition of the form:

$$\underline{X} = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \end{bmatrix} = \begin{bmatrix} \text{Retail Inventory} \\ \text{Factory Order Backlog} \\ \text{Averaged Retail Sales} \\ \text{Production Ability} \\ \text{Retail Sales} \end{bmatrix}$$

the simulation model then becomes the fifth-order system:

$$\dot{\underline{X}} = A\underline{X}$$

with

$$A = \begin{bmatrix} 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & -1 & 0 & 1 \\ 0 & .125 & 0 & -.25 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

A state-transition matrix data generation program was used to exercise the model with the initial conditions specified in the reference over a time frame of 0 to 49 units and a step size of 1 unit, giving a total of 50 state vector output points of 5 components each. The state vector values were incrementally loaded into the plot arrays as the simulation progressed. The plotter routine was called at the end of the numerical processing, with the results shown in figure 2. The first four curves, representing the first four components of the state vector, were plotted with the characters A, B, C, and D respectively. The minimum, maximum, and mid-point values for each curve appear at the top of each page of the output in ascending order. Note that the values for E are constant at a level of 120.000, indicating that the fifth state vector component remained at this constant value throughout the run. This aspect of program behavior is also used when plotting less than the full complement of five curves, as the data in a constant vector would plot as a straight vertical line, and are deleted from the plot output to maximize readability. Also note that the plot in figure 2 used IFLAG = 0, and the data point count generated by the plotter appears in the left hand margin.

A brief note about the scaling procedures employed by the program is in order. Under normal operating conditions, scaling is accomplished automatically for each curve without user intervention. If, however, a common scale for each of the five curves is required, the main program must be structured to supply the upper and lower limits of each curve's plot scale in two entries appended to each data array, and to set the point counter to a value equal to the number of the actual data points to be plotted plus two to force the scaling section to consider the supplied values. In order for this procedure to work properly, the lower limit specified must be less than or equal to the smaller expected data point, and similarly, the upper plot limit must be greater than or equal to the largest expected data point.

References

(1) Jarmain, W. E., ed., Problems in Industrial Dynamics, MIT Press, 1963, pp. 118-124.

(2) Bauer, C. S. and Capehart, B. L., "State Variable Methods for Digital Simulation of Economic and Inventory System Models," paper presented at the 38th National Meeting of the Operations Research Society of America, October, 1970

REAL-TIME SPECTRUM ANALYSIS OF SONAR SIGNALS USING A COMPUTERIZED ACOUSTIC ANALYSIS SYSTEM

Mr. F. A. RYDER

Hydrospace Research Corporation
South Florida Laboratory, Ft. Lauderdale, Fla.

For some time, the sea-going computer has been proving its worth in a wide variety of applications. [1,2] In this presentation, we describe an acoustic analysis system built around a small general-purpose computer, and consider the role it has played, and the influence it has exerted in extensive at-sea tests of a sophisticated sonar system. Particular attention is paid to the use and value of on-line acoustic data in improving operator effectiveness in Research, Development, Test and Evaluation (TDT&E).

The acoustic analysis system, Hydrospace Research Corporation System 1360, is shown in its shipboard installation in figure 1. The system is a specialized hybrid of analog and digital subsystems organized so as to provide effective acquisition, on-line processing and output of acoustic data in standard format, for immediate use by the operator. This capability is of obvious value in field experimentation as well as in operational usage. Based on the on-line spectral data, the operator or experimenter can verify overall acoustic system performance over the frequency range of interest, detect abnormalities, modify procedures, etc. In addition, the ability to acquire, present, and compare data under changing conditions in the course of exercises, constitutes an effective mechanism for training and familiarization of new personnel with sonar information in general and with specific characteristics of acoustic gear.

To illustrate the benefits of a rapid on-line analysis capability from the standpoint of operator effectiveness, we should first outline certain unique aspects of the sonar evaluation program referred to above.

The sea-trial series in which the acoustic analysis system was initially employed was basically an extended Reliability and Maintainability evaluation of a state-of-art sonar. The R & M program was undertaken in order to identify and investigate possible deficiencies in this aspect of the sonar system performance so that corrective measures could be applied in the development of production specifications and in the production phase. Due to the nature of the system and the R & M objectives, the evaluation program necessarily involved a great deal of at-sea test time over an extended period.

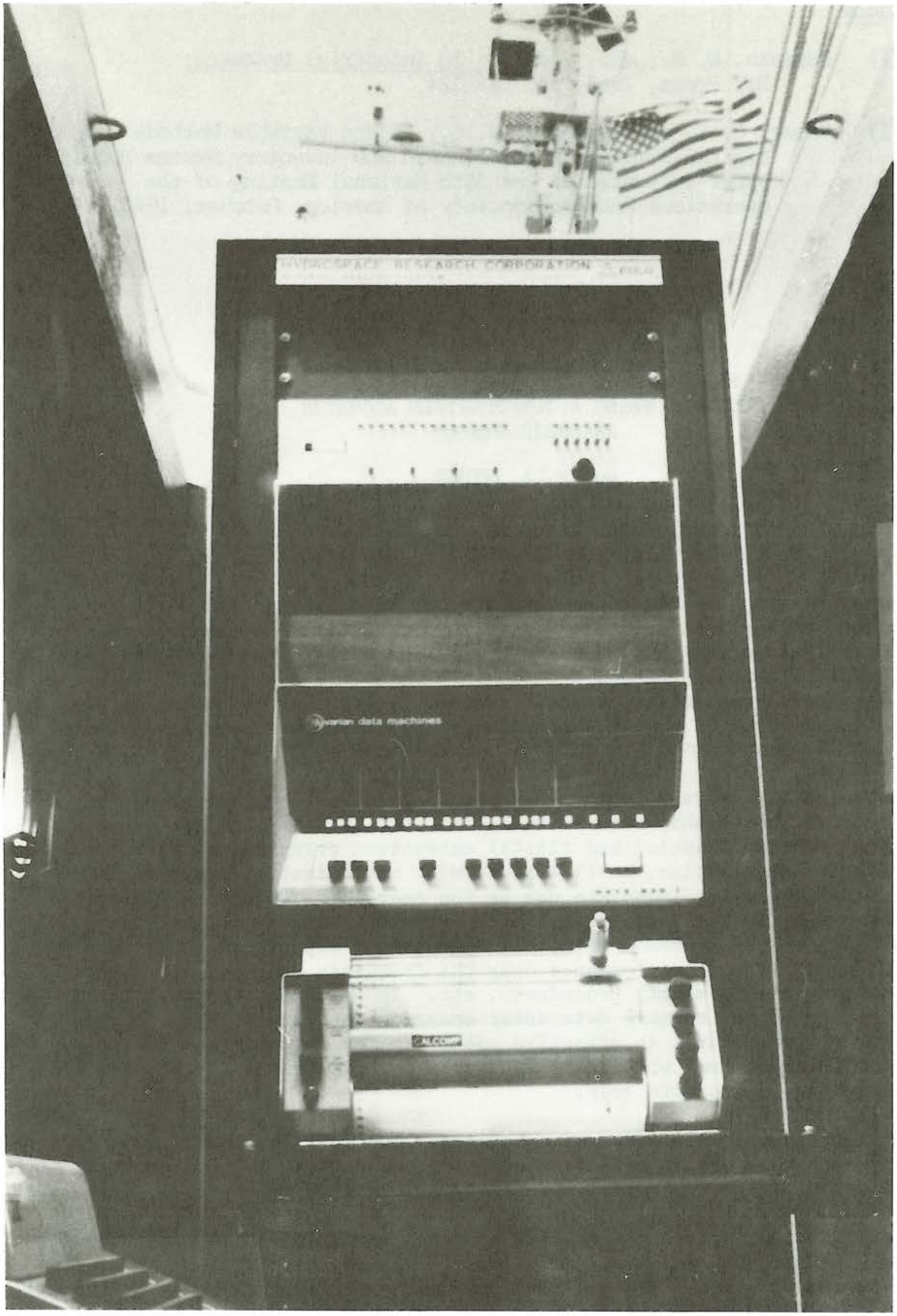


Figure 1. Computerized Acoustic Analysis System in Shipboard Installation

From a technical standpoint, the R & M program obviously offered an excellent opportunity for in-depth acoustic performance investigation as a follow-up to previous developmental work. From a personnel standpoint, however, the extensive sea-time planned for the R & M work added certain constraints.

For both technical and economic reasons, the senior engineering personnel most familiar with the system under test, and with the characteristics of the acoustic data obtained from it, could not participate heavily in the continuing at-sea work. The R & M tests, however, demanded that large quantities of valid acoustic data be obtained routinely. In addition, it was essential that the results of additional R & D investigations be available on a timely basis, for optimum value to the continuing developmental effort.

These were rather demanding program requirements for the technical field crew. Any lack of experience, at least, in the acquisition and analysis of acoustic data, would obviously jeopardize program objectives. Conventional on-line acoustic analysis is usually accomplished by producing a strip chart recording of one-third octave filter band levels, in db re 1 volt, using either a multi-channel recorder and parallel filters, or a single channel analyzer with a mechanically swept filter. In either case, it is necessary to calibrate the recorder, read off the band levels in dbv for each band, usually with some eyeball averaging, and apply the appropriate corrections for hydrophone sensitivity, system gain and, if desired, bandwidth, to produce spectral information in acoustic units such as db re 1 microbar in a 1 Hz band. This is not only tedious and time consuming, but also involves considerable opportunity for introduction of human errors. If, as is usually the case, the data must be plotted for analysis and presentation, and subjected to further statistical analysis, the amount of time and effort involved becomes formidable.

In view of the amount of data required in the sonar evaluation, with the most experienced personnel unavailable for extended work in the field, the acoustic measurement requirements posed a significant problem. An effective solution was found in the computerized acoustic analysis system, which was shown in figure 1. This system was installed on the HRC test vessel R/V DANIEL L. HARRIS, a converted sub chaser, in the summer of 1968, and has operated reliably in both R & M and R & D investigations through an extensive and continuing series of sea trials. It has been removed and reinstalled several times during ship overhauls and other interim periods, and has survived several storms, and a generally rugged environment while satisfying the stringent program requirements for a large quantity of high-quality acoustic data on a short time scale. Before considering the impact that the on-line processor has had on the field tests, and specifically on the effectiveness of the technical crew, we will outline pertinent aspects of its design and operation. (The system and its capabilities have been described in detail previously).[3]

As shown in the block diagram in figure 2, the acoustic analysis system is built around a small general-purpose computer, and includes conventional one-third octave filter sets, a high speed multiplexer and A to D converter, digital plotter and teletype. (We might note at this point that although the following discussion centers on the "traditional" and widely used one-third octave analysis, software packages have been developed for the 1360 to provide alternate processing modes. Some of these additional capabilities are described below).

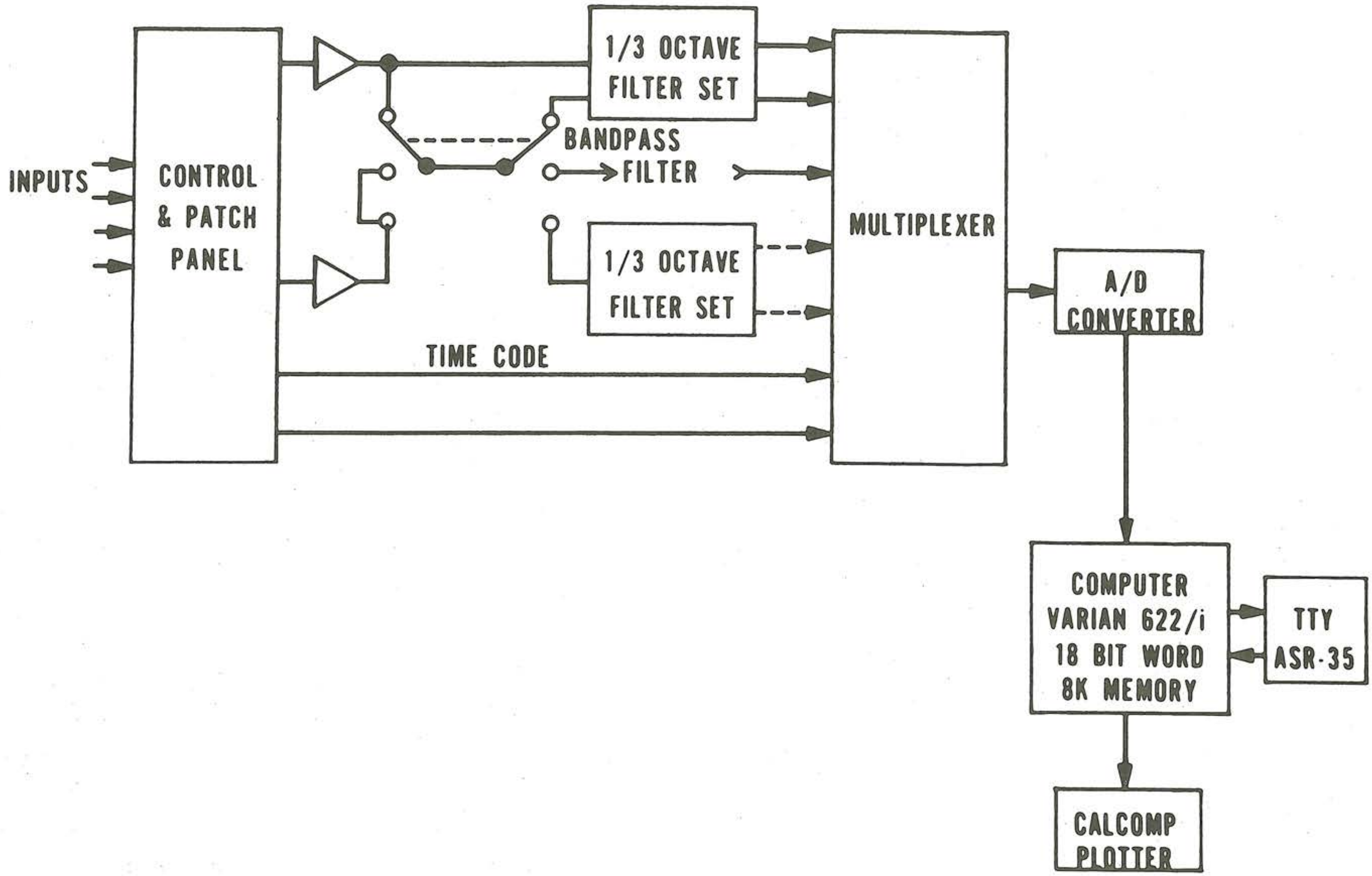


Figure 2. Acoustic Analysis System Block Diagram

For spectrum analysis in one-third octave filter bands, the normal processing procedure involves:

1. Squaring the output of a particular filter;
2. Integrating; and,
3. Converting to the logarithmic scale.

With calibration and system gain correction, the resulting band level can be expressed in decibels referenced to an appropriate sound pressure unit. The conventional output, then, is a plot of band levels for the one-third octave band center frequencies, over the frequency range of interest. Since there are 10 such bands per decade of frequency range, it is clear that conventional processing involves either a great deal of analog hardware for parallel processing, or low processing speeds, as a single processing channel is applied in turn to all filter bands of interest. Neither of these alternatives are favorable for on-line work in the field.

These drawbacks are avoided in the 1360 by taking advantage of the high-speed capabilities of the digital computer to execute the necessary signal processing steps, i.e., squaring, integration and log conversion, on the digitized outputs of conventional one-third octave filters. This hybrid approach, combined with a unique sampling technique, increases the overall frequency range, or total number of one-third octave bands, that can be processed essentially simultaneously.

The filter outputs are applied in parallel channels to the multiplexer/A to D converter, where they are sampled, digitized, and entered into the computer in sequence, under program control. Normally, the upper frequency limit for valid processing depends on the channel scan rate at which the filter outputs are sampled. This establishes the Nyquist frequency for the sampling process. In the present case, due to processing time required for each digitized input, this is limited typically to the order of 200 scans of 40 channels per second.

In the 1360, the sampling rate restriction is avoided by the device of randomizing by computer control the initial channel, or effectively the initial frequency band, sampled in each scan. This has the effect of increasing the upper frequency limit, at which valid measurements can be made, to a frequency given by the conventional Nyquist frequency multiplied by the number of channels, or filter bands, covered in each scan. The upper limit is increased still further by injecting a random delay, equal to some fraction of the basic sampling interval, between consecutive scans.

The net effect of this random sampling scheme is the ability to make valid acoustic measurements, with no aliasing errors, to frequencies as high as 100 kHz, in spite of channel scan rates on the order of only 200 scans per second. For a given sensor or sonar output, measurements can be made over an operator-specified frequency range at a rate limited basically by the operator-specified integration time. Such measurements can be retained in a designated section of core memory for later use, or can be printed, plotted, or transferred to punched paper tape. (The output operations, of course, add to the basic time requirement for a given measurement if they are performed on-line).

The resulting system is a powerful analytical tool that combines compactness, essential to field operations, with flexibility of operation built into the basic processing software package. Before considering the software provisions for operator-machine communication, we might review briefly the physical configuration of the system as it has been employed in the sonar program. In its original shipboard configuration, shown in figure 1, the entire system, with the exception of the teletype, was mounted in a standard 19" instrument rack. With the teletype at right angles to the main rack, the seated operator has convenient access to all controls essential to the operation of the system, and can readily monitor output data.

Subsequently, the digital plotter shown in the photograph was removed to another rack and replaced by a pair of buffer amplifiers and a patch panel. This was a data quality control measure, so that the operator of the acoustic analysis system has complete control over selection of the sonar signal to be measured and over gain setting. This was found to be highly desirable to alleviate a human error problem in a normally hectic environment. The desired acoustic signal can be selected either manually, or by computer-controlled relay based on an operator-specified identification number. At present, the main rack also includes a high-speed paper tape reader, not shown in figure 1, for input of programs or previously acquired spectral data for further processing.

Flexibility of operation is achieved via teletype control of basic processing parameters and functions. Software development and refinement have continued throughout the program, leading to a powerful conversational operator language known as SPECTRAL, with an extensive complement of keyboard commands.[3] This approach maintains simplicity of operation while providing effective operator control. The sample computer-generated teletype copy shown in figure 3 suggests the flexibility of the SPECTRAL one-third octave analysis program. The first part of figure 3 contains examples of status logs, which are printed on request through the keyboard, or as specified in an operator program.

The "Quick Log" at the top of figure 3a is obtained by a two-letter command entered on the teletype keyboard. It lists all parameters pertinent to the one-third octave program. For example, "F" indicates the first filter band, or effectively the lower frequency limit, to be included in the spectral analysis. "N" specifies the number of filter bands to be sampled, and "I" is the integration time. (The latter is shown as 1 second in the example, but is naturally much greater than this in normal processing). Other letters designate the origin, vertical scale (db per division), and plotting symbol to be used by the digital plotter, run number, sonar output to be processed, etc.

Below the "Quick Log", several individual status logs are listed. This is an operator convenience, allowing a check of an individual parameter, when the entire listing is unnecessary. Each individual log is requested by striking "L" followed by the corresponding designator letter.

Each of the processing, or run parameters shown in the "Quick Log" can be incremented or otherwise changed by the operator. A two-letter command informs the machine that a new condition is to be established, and the operator then enters the new value for the designated parameter via the keyboard. For example, "EI" followed by "60" establishes an integration time of 1 minute for subsequent measurements.

An additional set of two-letter keyboard commands controls program functions. For example, the operator can initiate an integration or measurement of filter band levels, request a print-out of band levels, subtract a reference spectrum from the measured spectrum, and produce a plot or overplot of spectral data.

```
    ØLOG
  1 A        Ø B          1 C          Ø E          9 F          Ø K          Ø J
  Ø M        1 N          Ø R          Ø S          Ø T        Ø.Ø G        1.Ø I
Ø.Ø O      1.Ø V


    LOG HYD.#                1
    LOG EVENT                Ø
    LOG BRG                  Ø
    LOG TICK                 Ø
```

a. Quick-Log and Status Logs

```
        PROG.
1ØØ ACQU:
1Ø1 SUB #   51:
1Ø2 BLVLS:
1Ø3 REPLOT:
1Ø4 P.TAPE:
1Ø5 END:
2ØØ
```

b. Simple Operator Program

Figure 3. Sample Teletype Copy

In the conduct of an experiment, then, the acoustician, engineer, or technician needs only a listing of the letter designators associated with the various parameters and controls. As far as possible, these have been selected based on a mnemonic relation to the corresponding function.

Figure 3b illustrates an additional level of automation available in the system software through an operator programming mode, in which a series of procedures, parameter changes, output functions, etc., can be specified in advance, using the keyboard instructions described above. The system will then perform the specified series of operations upon an instruction to execute the program. Such programs can be made to run repetitively, if desired, as a further convenience to the operator in a repeated series of identical measurements. The operator program in figure 3b initiates an "acquisition" or integration of band levels, subtracts a reference spectrum, and prints and plots the resulting spectrum. This is, of course, a very simple example and a much more complex sequence of operations, including DO loops, can be accommodated.

Several additional features were built into the basic analysis program. A calibration mode, for example, makes it possible to insert the various system functions, based on gain and hydrophone sensitivity, so that acquisition of an appropriate calibration voltage automatically calibrates the analysis system. Measurements can then be obtained directly in sound pressure level, referenced to the desired units. Gain changes can be accounted for through the keyboard. If desired, range corrections, based on the assumption of spherical spreading, can be automatically applied by designation of the desired range R in yards. Spectra can be stored in several reference locations, and manipulated, for example, to compute the difference between specified spectra. Data can be expressed as one-third octave band levels and/or corrected to equivalent 1 Hz spectrum levels. Spectra can be printed, punched on paper tape, plotted, and overplotted, complete with coding symbols. Figure 4 shows a typical computer-generated spectral plot of one-third octave band level measurements (note that plotting symbols can be automatically incorporated in the plots if desired).

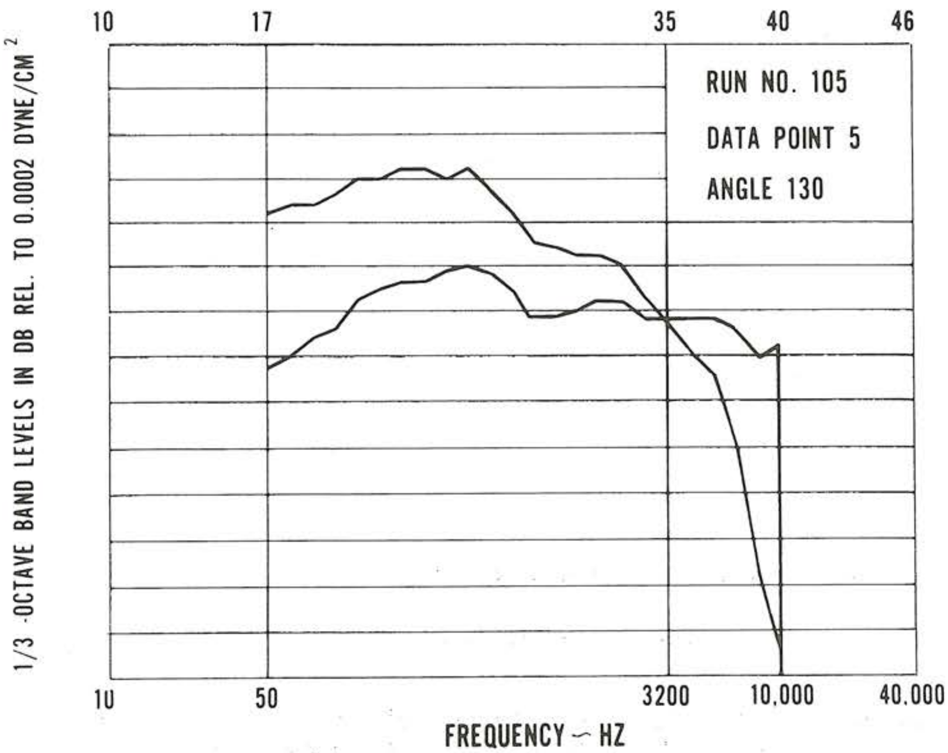


Figure 4. Sample One-Third Octave Measurement Plot

A separate extremely useful program is available for statistical analysis of spectral data, providing sample mean and standard deviation. The averaging can be done logarithmically, using data expressed in db, or linearly, following conversion from the db scale. As with the basic analysis program, results can be printed, punched on tape, and plotted in various combinations, and can be manipulated to yield additional useful plots such as sample mean with confidence limits based on the Student t distribution.

Other software packages have been developed to provide optional processing modes. It is possible, for example, to cross-correlate two acoustic signals, using parallel one-third octave filter banks. In general, the additional programs incorporate the same elements of flexibility and operator control as demonstrated in the basic one-third octave analysis program described above.

To conclude this description, we should point out that the acoustic processor is not limited to the physical configuration shown in figure 1, or to the application described in this presentation. A modular system has been built, using standard instrumentation housings, suitable for truck, or submarine installation. In this configuration, a truck-mounted system has been used in the field for aircraft noise measurements at airports or test facilities. Special software has been developed to produce on-line measurements of Effective Perceived Noise level, in accordance with FAA specifications, and the system has been approved for aircraft-type-certification noise measurements. Finally, a much more elaborate shore-based version of the processor has been assembled in Hydrospace Research Corporation's (HRC's) laboratory. This incorporates a digital tape unit and magnetic drum, together with other refinements, and is currently employed in a major software development effort in support of the sonar evaluation program. Eventually, this system also will be re-configured for shipboard use.

We discussed previously the various problems related to personnel experience, data availability, etc. that were alleviated by the provision of an on-line analysis capability. We will attempt to complete the picture by reviewing specific effects of this capability from the standpoint of personnel effectiveness.

It should first be emphasized that training *per se* was not a direct objective of the program. Although, a brief orientation program was conducted, during a break in the trial series, the benefits in this area, which were derived from the provision of the acoustic analysis system in the shipboard laboratory, were essentially side effects. Undoubtedly, some of these effects could be considerably enhanced in a formal training program either in the field, or through simulation.

Based on our experience in the sonar evaluation program, the benefits referred to above may be summarized as follows:

1. Rapid familiarization of technical crew members with measurement operations alleviates problems due to unavoidable personnel turnovers and scheduling conflicts.

2. On-line availability of data plots, without tedious manual manipulations, improves understanding of sonar system performance and facilitates relationship of data characteristics with test parameters.

3. Processing speed and flexibility promotes operator participation in development or refinement of test procedures, data comparisons, etc.

4. Calibration and measurement with the computerized system enhance understanding of the computations involved in conventional on-line analysis techniques.

In short, the acoustic data itself and the operation of the sonar system under test become more meaningful in a shorter period of time. Also, due to the simplicity of operation of the analysis system, new members of the technical crew can be brought up to speed quickly on data acquisition, and optimum use of at-sea time can be achieved.

From another standpoint, it is perhaps obvious that, the same data that contributed to effective technical crew training was also available to benefit the sonar evaluation program more directly, through its quantity, quality, and timeliness. In addition, an operator feedback mechanism developed with increasing experience in the use of the processor and understanding of its potential. For example, rapid test procedures were devised to allow periodic checks of sonar system grooming, replacing time consuming and tedious conventional procedures. Test plans were arranged and runs were scheduled so that the temporary storage capacity of the computer could be utilized effectively, for example, in the generation of spectral overplots for the comparison of different test conditions. Finally, this feedback mechanism applied to the acoustic analysis system itself, providing a useful input in the development and refinement of software, and occasionally leading to modification or re-configuration of system hardware.

The provision of an on-line analysis capability, then, has contributed to an RDT&E field test program in two related but basically distinct ways:

a. Improved operator effectiveness; and,
b. Timely production of required data.

Based on these observations, we believe that an on-line processor can be applied to advantage in subsequent operational deployment as well as in a formal training program. A shipboard computerized processor can facilitate target identification, and allows rapid and efficient routine checks of sonar system grooming, self noise, calibration, etc. In addition, the immediate availability of spectral data contributes to an understanding of the effects of operational parameters on system performance, and provides an effective mechanism for continuing in-the-field training and review. Finally, in a formal training application, the processor leads to rapid familiarization of personnel with acoustic data, as well as with the procedures involved in the acquisition and analysis of such data. Full utilization of the speed and flexibility of the processor in conjunction with conventional or state-of-art sonar displays can undoubtedly enhance the trainee's understanding of sonar information and the capabilities and limitations of the sonar system.

References

1. "Taking Computers to Sea", J.D. Mudie, Proc. Marine Technology Society Conf., Washington, D.C. 1970.

2. "Applications of Sea Going Computers", Trans. of Marine Technology Soc. Symposium, 1969.

3. "Real-Time Spectrum Analysis in the Field Using a General-Purpose Computer", E.M. Fitzgerald, A.A. Petrini and J.K. Zimmerman, paper presented to Acoustical Society of America, San Diego, Cal., November, 1969.

Acknowledgements

The original development of the HRC 1360 was accomplished by the San Diego division of Hydrospace Research. J. Zimmerman, A. Petrini and E. Fitzgerald of that division provided much pertinent material for this presentation.

ELECTROACOUSTIC SIMULATION OF COMBAT SOUNDS PRESENT STATE-OF-THE-ART AND FUTURE GOALS

MR. ALLAN P. SMITH
Head, Audio Test and Evaluation Facility,
Naval Training Device Center,
Orlando, Florida

INTRODUCTION

Electroacoustic simulation of combat sounds is of considerable interest in military training. The cost of weapons and ammunition, personnel required to operate the weapons, and danger to the trainee, are some of the reasons why the use of operational weapons for training activities is undesirable. The electroacoustic simulation of combat sounds such as rifle or artillery fire is a two-part process which requires recording the sound of the weapon to be simulated, and the electroacoustic reproduction of the sound recording. Advantages of the electroacoustic recording and reproduction of combat sounds are as follows:

a. Once the master recording of a weapon sound is made, unlimited copies of the recording can be made to supply numerous users as well as the establishment of a library of combat sounds, which would serve many training locations.

b. After the initial equipment investment, operation of a combat sound reproduction system is economical. Automation of the reproduction system can free instructors for other training functions.

Before the state-of-the-art technology in electroacoustic recording and reproduction systems can be discussed, it is necessary to define the nature of combat sounds, and the goal to be achieved in the electroacoustic simulation process. The sound produced when a rifle is fired is essentially a high intensity pulse of energy, which has a steep wavefront and rapid decay. Peak sound pressure readings of 180 decibels have been measured at the muzzle of a rifle as it is fired. Because of the sharp wavefront of the pulse, it is estimated that the bandwidth of the sound is from d.c. to beyond audibility (15 kHz). The subaudible component of the pulse produces a pressure wave that is felt rather than heard. The exact degree of electroacoustic simulation of combat sounds will largely depend on the end use of the simulation. To simplify the establishment of acoustic requirements for an electroacoustic simulator of combat sounds, three categories or degrees of simulation are defined as follows:

a. Highest degree of simulation in which exact simulation of sound intensity and bandwidth is required for simulation in an outdoor environment.

b. In training situations, where the trainee is close to the source of sound simulation, it may be desirable to limit the sound intensity to the established threshold of pain at 130 decibels so the trainee is not required to wear ear protectors to prevent hearing impairment. The simulated sound should have as wide a bandwidth as technology allows to achieve as much realism as possible. The training situation will also primarily be an outdoor one.

c. For classroom sound reproduction systems, high intensity, wide bandwidth sound reproduction is not required for classes in sound recognition. Smaller reproduction systems can be used to provide the bandwidth and sound intensity required for this purpose. This system will be smaller in size and lower in cost than systems required for outdoor simulation.

The sound emitted as a weapon is fired produces the sound distribution characteristics of a spherical sound source. The omnidirectional sound distribution of the combat sound is difficult to capture via the magnetic recording process and electroacoustic reproduction. Figure 1 is a graph of the attenuation of the sound pressure level versus the distance from the source of sound to the trainee. The sound pressure level generated by the electroacoustic reproduction system should be calculated to give the required sound pressure level at the trainee position. This calculation will provide the sound level requirement for the reproduction system's acoustical output capacity. Once the output capacity of the reproduction system is determined, selection of components for the reproduction system can be accomplished. A factor that is frequently overlooked is the attenuation of high frequency energy over long distances during high humidity weather conditions. Attenuation of high frequency energy will change the sound of the weapon as the distance of the sound source from the trainee varies. At a location close to the sound source, the weapon sound will have a sharper sound than that heard, when the trainee is at a greater distance, from the weapon. In the recording and reproduction process, it is important to capture as much of the full high frequency response of the combat sound as possible. The reproduction system will then generate a sharp pulse, which will receive high frequency attenuation, in travelling the distance from the simulator to the trainee. If the recording is made with the microphone at a considerable distance from the weapon, the sound heard from the simulator by the trainee will be excessively dull and unrealistic. Therefore, in the process of recording combat sounds it is important for the high intensity recording microphone to be placed as close to the weapon as possible in order to capture the full pulse spectrum.

CURRENT STATE-OF-THE-ART IN MAGNETIC RECORDING TECHNOLOGY

Recording combat sounds by the magnetic tape recording process requires a combination of high quality recording equipment, and skillful recording techniques in order to overcome the dynamic range limitations of magnetic tape. The dynamic range of real-life combat sounds is often in excess of 130 decibels. With the current state-of-the-art technology in magnetic recording, the maximum dynamic range is 70 decibels from a reference level of 3% total harmonic distortion to the ear weighted noise level of the tape. While the inability to record a 130 decibel dynamic range signal is disturbing, several techniques may be used to improve the recording. First of all, the ambient noise level at a location for recording combat sounds will probably be above 75 decibels. In addition to recording the sound of the weapon, ambient noise is also recorded. Therefore, the actual recording of the combat sound will have a peak signal to ambient noise ratio of 130 decibels minus 75 decibel ambient noise for an actual dynamic range of 55 decibels. Further improvement in the recording process can be achieved with the use of a peak limiter, which will cut-off peaks, above a preset level and prevent magnetic tape saturation. Adjustment of the peak limiter to provide peak limiting plus compression will enable a higher average signal level to be recorded without producing distortion and if the steep wavefront of the noise pulse is maintained, the trainee will probably not be able to detect that the peak is missing. Further improvement of dynamic range can be had with the use of the Dolby Compressor/ Expandor Noise Reduction System. An improvement of 15 decibels can be achieved with the Dolby unit to a maximum signal to noise ratio of 80 decibels. Use of the Dolby unit, during the recording and tape duplication process, can help maintain the dynamic range of the original recording.

Condenser microphones provide linear pickup of peak sound pressure levels as high as 180 decibels. The best transient response is obtained from a condenser microphone system using a 1/8-inch diameter diaphragm.

Frequency response of this condenser microphone is flat from 10 Hz to 100kHz and, therefore, the steep wavefront of a rifle shot can be maintained through the microphone transducer. However, the extremely low signal produced by the microphone requires a preamplification system with very low noise, and a high overload capacity to handle the peak signal amplitude.

CURRENT STATE-OF-THE-ART IN SOUND REPRODUCTION TECHNOLOGY

For this discussion of the current state-of-the-art in sound reproduction technology, the goal will be the best system to satisfy the simulation situation (a) defined earlier. The other simulation situations will all be variations of situation (a). In order to satisfy this training situation, the peak reproduced sound pressure level should approach 180 decibels with a bandwidth from below audibility to beyond audibility. The size and cost of such a reproduction system will be high.

Sonic boom simulators have been constructed that will produce 150 decibels at the subaudible threshold range. This simulator uses the mechanical rupturing of two diaphragm assemblies connected to a long exponential horn to produce an N shaped waveform. This simulator is limited to reproduction in the subaudible threshold range, and requires that the ruptured horn diaphragms be replaced before the simulator can be activated for a second time. Clearly, this type of simulation system would be unpractical for military training, where multiple explosions are often required.

The use of loudspeaker mechanisms for combat sound reproduction systems is difficult because of the performance limitations of loudspeaker mechanisms. In order to reproduce subaudible signals, the loudspeaker system has to move a great quantity of air. This requires a massive array of large diameter cone loudspeakers. The displacement required to reproduce a 20 Hertz signal for various diameter loudspeakers is shown in figure 2. Limiting this frequency range to that above 30 Hertz is a practical solution. Even at this frequency, a large quantity of air will have to be moved and multiple speaker arrays will be required. While a 15-inch diameter loudspeaker will move a greater quantity of air than a 12-inch unit for a given cone displacement, the increased mass of the loudspeaker cone will limit its ability to respond to a steep wavefront signal. Obviously, a series of different diameter loudspeakers will be necessary to preserve the waveshape and directional characteristics of the reproduction system. Figure 3 shows the effect of frequency on the directional distribution characteristics of a cone loudspeaker. Condition A is the distribution pattern produced, when the wavelength of the sound being reproduced is equal to 4 times the diameter of the loudspeaker cone. Condition B is observed, when the wavelength of the sound is equal to the diameter of the cone. When the wavelength of the sound is 1/4 the diameter of the cone, condition C results. The sound distribution pattern produced under condition C will be useless for sound reproduction systems that must cover a wide angle of sound distribution. A practical approach to the simulation of combat sounds is the use of a loudspeaker system using four different diameter driver elements. An array of four 12-inch low frequency speakers in a 16 cubic foot sealed enclosure will provide reproduction in the range from 20 Hz to 100 Hz.

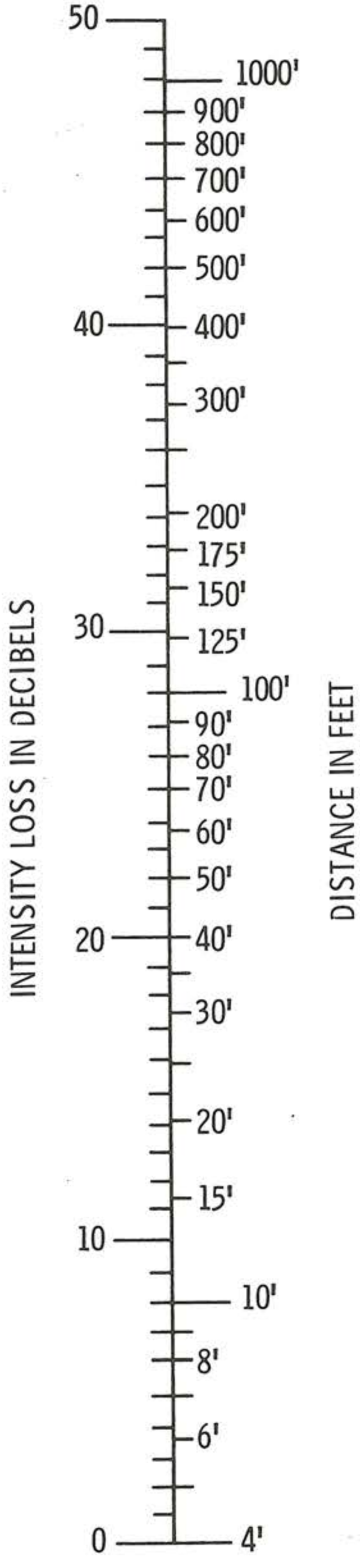


Figure 1. Intensity Loss Scale

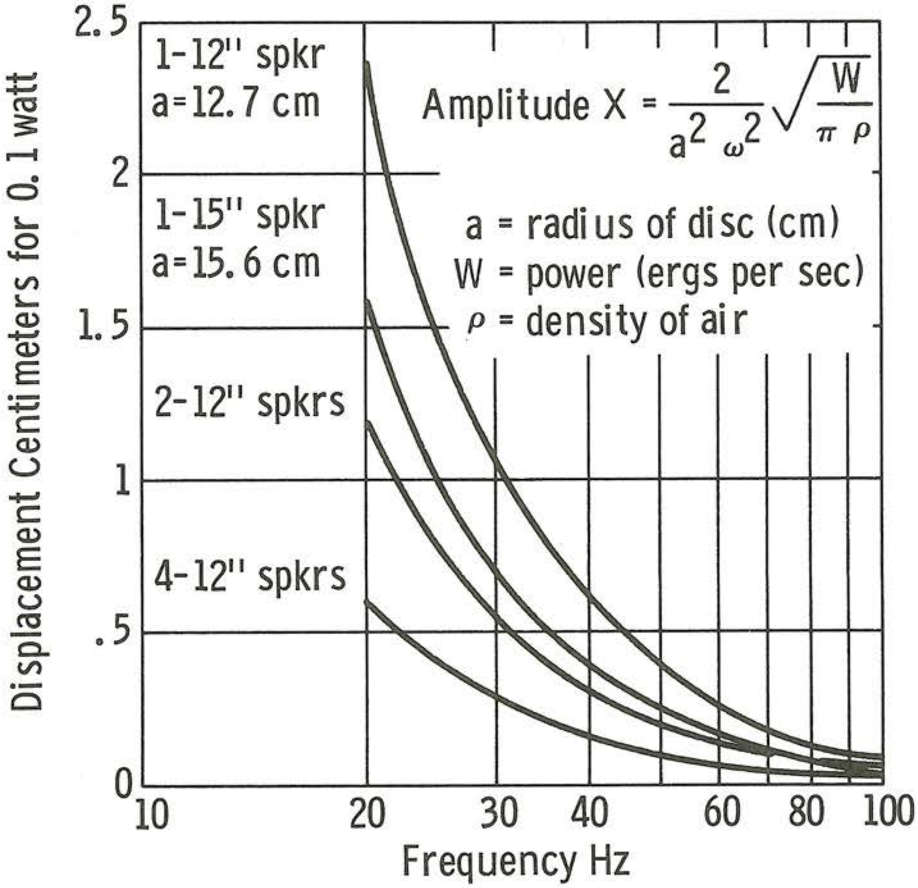


Figure 2. Displacement vs Frequency at 0.1 Watt Output

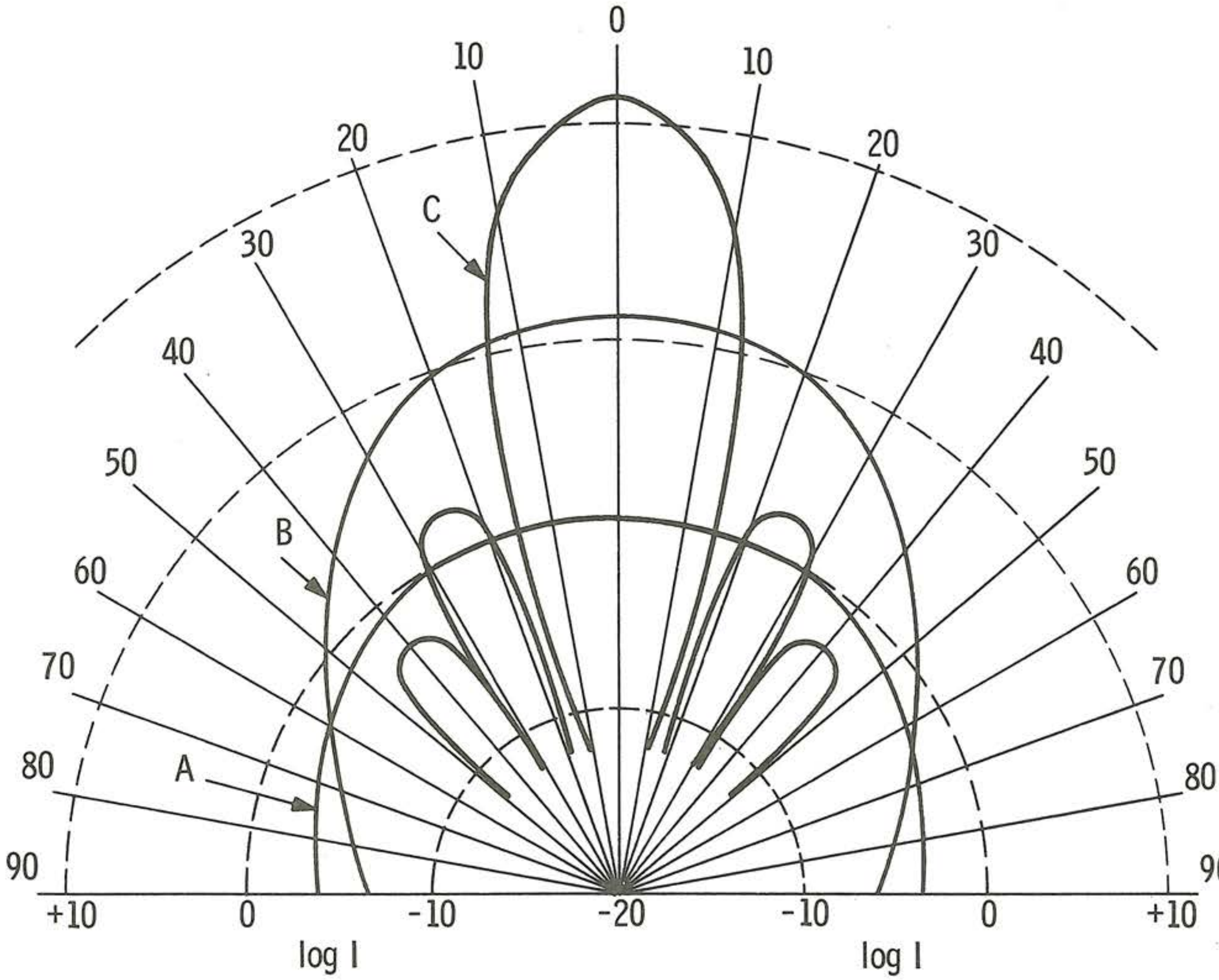


Figure 3. Polar Radiation Patterns of a Plat Piston
(Log I is plotted against θ for (A) λ = 4d, (B) λ = d, and (C) λ = d/4)

A three-way columnar system, shown in figure 4, provides columnar arrays of the remaining three other diameter speakers. The use of columnar arrays for the three upper portions of the sound reproduction system permits the use of multiple smaller cone speakers to move large quantities of air, and still maintain optimum transient response. The use of different diameter arrays assures constant directional characteristics to 15kHz over a 90-degree distribution angle. An array of six 8-inch speakers covers the spectrum from 100 to 800 Hertz. The nine 4½-inch speaker array operates in the range from 800 to 2500 Hz, and the eight 2-inch speaker array extends the range to 15kHz. This configuration, used in combination with an electronic crossover system, using 6 db/octave filters, and three 100 watt rms audio power amplifiers will produce a sound pressure level of 130 decibels at 4 feet from the system. For higher acoustical output capacity, multiple arrays of loudspeakers and additional amplifiers may be used, increasing the sound pressure level by 3 db each time the number of loudspeakers and amplifiers is doubled. A typical installation consisting of a professional grade tape reproducer, the Dolby Noise Reduction System, a three-way columnar loudspeaker system, a low frequency supplement system, three 100 watt power amplifiers, and miscellaneous accessories will cost approximately $5,500. To add another three-way columnar system, the bass supplement system, the three power amplifiers and accessory cabinetry will cost an additional $2,500 to achieve a 3 db increase in acoustical output.

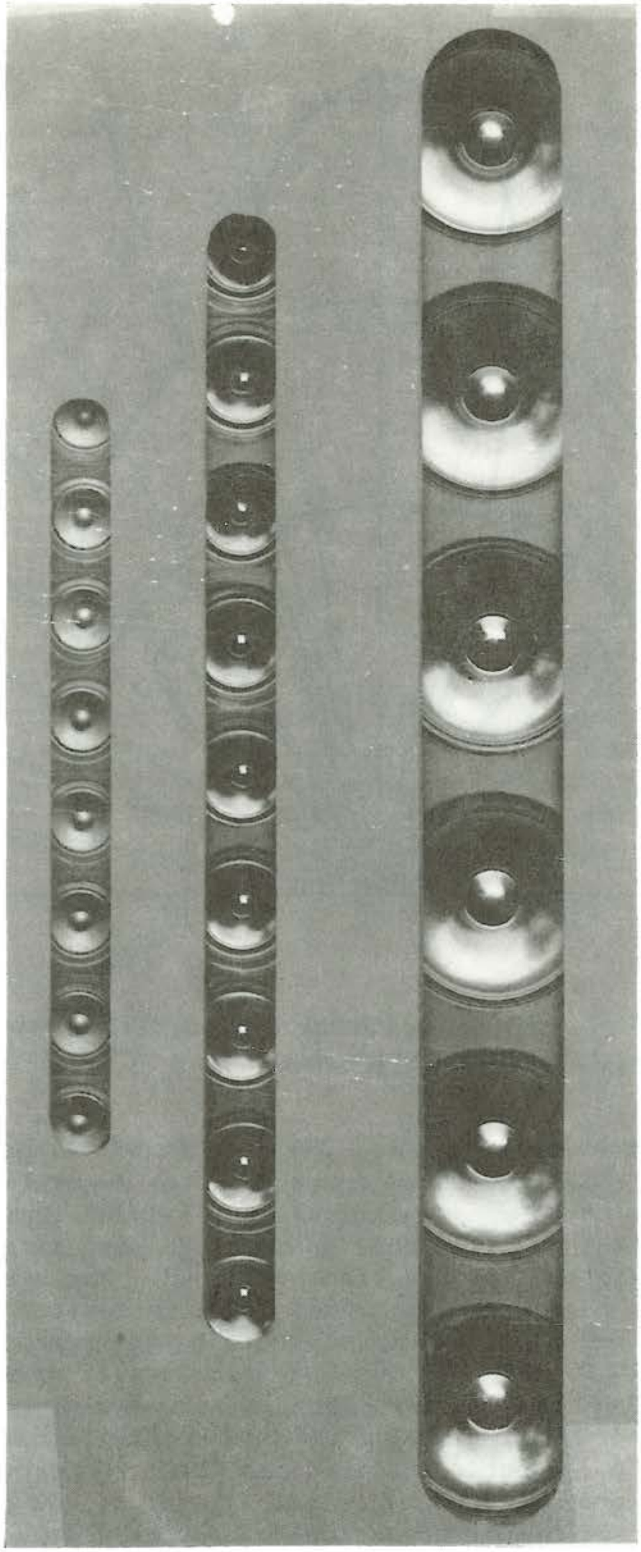


Figure 4. Photograph of the Three-Way Columnar Loudspeaker

Horn loudspeakers are noted to be a higher efficiency than cone units. However, their 6 db increase in efficiency is wasted when horn systems must be used with the lower efficiency cone loudspeakers for reproduction of frequencies below 300 Hz.

Multiple speaker systems, which use different diameter loudspeakers for various parts of the sound spectrum, must be tied together with a common distribution system, which separates the sound spectrum into bands, and then channels the respective band to the correct loudspeaker element. This distribution system is usually a passive inductor-capacitor network configuration known as the crossover network. It is the task of the crossover network to provide a smooth transition of sound from one loudspeaker mechanism to the one in the adjacent band. The topic of crossover network action is complex enough to be a study in itself, but for this discussion, it is sufficient to say that the connection of the crossover network's inductor in series with the low frequency loudspeaker causes a restriction on the transient response of the low frequency speaker, and the ability of the power amplifier to provide proper damping action. A typical effect of this series inductor is to cause the low frequency loudspeaker to produce a ringing characteristic, when activated by a sharp pulse signal. A significant improvement in optimizing loudspeaker transient response is through the use of electronic crossover networks and multiple power amplifiers. The electronic crossover network uses resistor-capacitor filter networks with buffer amplifiers to separate the sound spectrum into the required bands. A separate audio power amplifier is then used for each band's amplification, with the respective loudspeaker connected directly to the amplifier without any series elements to destroy transient response. The electronic crossover concept offers further advantages in lower intermodulation distortion, lower overload distortion, better transient response, and higher peak power output capacity. The Marine Corps Education Center at Quantico, Virginia is currently using a pair of three-way columnar loudspeakers with electronic crossover networks, and multiple 80-watt power amplifiers to provide an indoor combat sound reproduction system for use in amphibious assault training at Ellis Hall.

CONCLUSION

This paper has described some of the effort to date on behalf of the development of combat sound reproduction systems. A detailed study of the peak sound pressure level, produced by various combat weapons as well as waveform and spectrum analysis is needed to provide the information necessary for further investigation of combat sound reproduction systems. Perhaps the development of new mechanisms for transducing electronic signals into acoustical energy is required. There is much work to be done in the area of combat sound recording and reproduction and it is hoped that electroacoustic simulators capable of generating peak signals of 180 decibels will soon be found.

Figure 1. Ground Training Devices for Pilot Training

APPLICATION OF ADVANCED SIMULATION TECHNOLOGY TO PILOT TRAINING

MESSRS. J. F. SMITH AND D. W. SIMPSON
Link Division, The Singer Company

INTRODUCTION

For many years flight crew training followed a very traditional pattern; pilots were required to practice maneuvers in an aircraft for the purpose of developing skill levels sufficient to pass a rating check. Each new training program was modeled after those preceding; changes were minimal.

Later, as a result of the ingenuity of personnel concerned with training problems, the use of ground training devices was introduced into pilot training programs. These trainers were first used for instrument flight training and later for procedures training. After several evolutions of ground-based trainers, each possessing increased training capability, managers of pilot training programs became increasingly aware that simulators provide a suitable training environment and achieve many training objectives in a more efficient manner and with greater safety than the aircraft they simulate. At the present time, flight simulators have progressed to a point where airline training center managers foresee using little or no aircraft time in upgrading pilots to new equipment qualification.

Even with increased emphasis on the use of ground training devices little attention was given to the role of the instructor. Simulator flight instructors were also burdened with such tasks as problem control and simulator operation, and thus were too overburdened to apply their instructional talents effectively. The result was less than maximum effectiveness in the use of modern ground training devices.

With the advanced digital computers and programming techniques now available, solutions to these instructor problems exist. Automated instructor aids such as problem initialization, malfunction insertion, and objective performance evaluation can relieve the instructor of much of his auxiliary workload, allowing him to assume his unique role as a manager of training.

AUTOMATED TRAINING FEATURES

Following is a discussion of some advanced training techniques that have been devised for use with modern pilot training in flight simulator complexes (the order in which the items are listed is irrelevant).

1. Rapid Initialization. Many years of pilot training have produced a general sequence for teaching flying. Generally, flight training begins with the instructor flying the aircraft to a safe altitude, and then allowing a student to examine the effect of control movements. Simple, basic maneuvers such as straight and level flight, medium turns, climbs, and descents are then practiced. These are followed by maneuvers of increasing complexity until the entire syllabus has been presented. This sequence of learning has proven successful and necessary only, when aircraft are used and, when safety of flight is paramount. However, since these first-learned basic maneuvers are required in all later flights, a considerable amount of expensive aircraft time is necessarily consumed in repeating these maneuvers for other than learning requirements. This is true for both instrument and contact flight activities in either beginning flight schools or professional pilot

training. While such inefficient use of expensive hours cannot be eliminated, when using aircraft, it can be eliminated when using simulators. Rapid initialization allows the instructor (or student) to quickly select a preprogrammed position and simulator configuration without flying to that position. The result is restricting practice to the desired training objectives, greater utilization of simulator, trainee and instructor time, and a significant reduction in costs. With the use of currently available computers, the number of preprogrammed starting points and configurations are almost unlimited.

2. Automated Demonstrations. Another technique commonly used in flight instruction is the demonstration of a maneuver by an instructor after which the student is permitted to practice the same maneuver. The demonstration of these maneuvers varies not only from instructor to instructor but also from trial to trial; this inconsistency provides a poor model for the student. By using a high-speed computer to drive the simulator, it is possible to present a consistently perfect (or purposely erroneous) model performance which may be used again and again by all students. Any number of maneuver demonstrations may be developed. This technique frees the instructor from the aircraft flying task and allows him to concentrate on insuring that the trainee understands the basic cues and subtleties necessary to perform the maneuver. These models also permit increased efficiency in the use of the simulator for solo student training flights, and may be used effectively to standardize instructors as well as ratings of performance.

3. Automated Sequencing of Maneuvers. An extended application of the automatic demonstration mode is the capability of preprogramming a sequence of maneuvers. Since each maneuver, or mission segment, is coded for individual selection it is a simple process for an operator to either program a series of maneuvers, or to call up new ones, if student performance indicates such to be desirable.

4. Automated Malfunction Insertion. An important aspect of all pilot training, particularly in aircraft with more complex systems, is the handling of malfunctions and emergencies. While some of this training can be taught in the aircraft, it is an expensive classroom. Since many of these procedures may induce safety of flight problems, or cannot be taught in the aircraft, the use of ground trainers is required for hands-on training. An additional consideration is that the handling of malfunctions and emergencies can best be taught if no artificial cues, such as observing the actions of an instructor or engineer, are provided. The use of computer-controlled malfunction insertion provides more realistic cueing (progressively worsening if appropriate), and realistic and effective training can then be achieved.

5. Monitoring Procedural Items. Early phases of pilot training involves the learning of new procedures as well as basic perceptual-motor skills. Once the basic piloting skills are learned, more advanced flight maneuvers are performed by simply using different combinations of these skills. On the other hand, new or added equipment usually involved learning procedure sequences which differ significantly from those learned earlier.

Since these procedures are well-defined, and can be described in terms of system logic, they are readily adaptable to monitoring by the computer software associated with modern simulator complexes. For the same reason, it is relatively simple to automate a training program for student use. This capability, when used in modern simulators, serves to relieve the instructor of a significant portion of this otherwise attention-demanding and time-consuming task. This capability will also permit effective trainee practice during solo simulator missions.

6. Automated Recording of Student Performance. In pilot training, as in other learning situations, it is necessary to determine trainee progress. Since the computer, which provides the brains for integrating all simulator components, uses basic aircraft performance data and computed derivatives to make the simulator perform, these same data may be output in objective terms to describe student performance. Such data on selected parameters can be made available in real-time to assist the instructor in his complex task and later as feedback to the student. These accurate objective records reduce the instructor's recording task significantly and thus allow him additional time to observe student activities, which do not lend themselves to objective recording.

7. Automated Performance Comparison. Pilot performance in several parameters such as ability to maintain desired altitude, airspeed, heading, rates of turn, rates of descent, and coordination are particularly adaptable to recording as described in (6). Once these data are provided, it is then a relatively simple matter to program the computer to compare these data with predetermined criteria, and to provide an immediate readout or printout of how student performance compares with predetermined criteria. Such records are extremely valuable in supplementing the instructor's overall evaluation.

8. Knowledge of Results. The annals of research literature, in the field of learning, are filled with studies which indicate that immediate feedback of information on the quality of trainee performance proves valuable in accelerating student learning. The capability of recording performance (6) allows the development of techniques for presenting the student with a comparison between his performance and some selected standard. The use of data, as discussed in (7), provides him with pass-fail data; however, at the start of training, it may prove more valuable to set the standards at a lower level and increase these standards with student progression, using these readouts as a method of "rewarding" student effort. Such manipulations can be easily executed, either manually or automatically, and the data presented in terms of digital readouts or some other means of information transmittal.

9. Adaptive Training. Considerable research has been conducted which indicates that learning of perceptual motor skills can be accelerated by varying task difficulty in a controlled, orderly way. This theory suggests that a motor skills task can be learned more quickly if made easier by some means until the skill is learned, and then increasing the difficulty level as performance improves until final criterion performance is achieved. One term for this is adaptive training. The computer capability of current and projected simulator complexes provides a means of using this training technique. However, there are differences of opinion among experts as to whether the changes in difficulty should be based strictly on student performance or whether a stepped increase in difficulty, based on time or trials, should be used. (Where good performance is rewarded by increasing the task difficulty, this is not necessarily a reward in the trainee's mind.) In either case, the simulator computer can provide this capability.

10. Self Confrontation (Playback). A final training feature, which is possible as a result of the computer capabilities discussed earlier, is recording a trainee's performance which can later be replayed. This feature allows the student and instructor to observe and analyze trainee performance in a relaxed atmosphere wherein the student is not distracted by performance requirements. A freeze and slow replay capability, such as currently used in sports television productions, as well as a fast forward selection mode, is also provided. This capability should be extremely valuable for increasing the effec-

tiveness of debriefings. However, the question, not yet answered, is whether or not such a feature is as valuable as additional real-time trials; since the playback, as now conceived, will require simulator time. Additional research is needed.

OTHER ADVANCED INSTRUCTION CAPABILITIES

The ten features discussed above reflect the use of digital computers to automate various training systems. There are two other simulator developments that promise to provide better instruction, and deserve mention. The first is the use of cathode ray tube (CRT) display systems to present data to instructors. In recent years, the combination of increased computer capability and reduced CRT costs has led to the use of CRT displays as instructional aids. Such systems are in use for presenting automated performance readouts to trainees; for presenting instrument readouts, check lists, and repeater visual displays at instructor stations; and for providing information to training observers and maintenance personnel. They have proven extremely versatile and effective and, since the information displayed may be computer-stored and recalled as needed, they also permit a savings in space that otherwise would be needed at the instructor's console. While performance records presented on CRT's are temporary, permanent records can be made by photography or electrostatic techniques.

CRT's should also be extremely useful in presenting animated or filmed maneuver descriptions. Recent developments suggest that a 3-dimensional picture can be presented, which may prove valuable for some applications, when displaying maneuver patterns.

A second instructional aid associated with computer utilization is the capability to provide automated audio briefings. With proper software application, it is possible to present a standard briefing to all trainees and recall all or a portion of these briefings for individualized instruction.

The preceding are some of the more significant capabilities that have recently become possible, but have not yet been fully exploited.

SPECIFIC APPLICATION

The features discussed include some which have recently come into general application with advanced simulator complexes, and some which are ideas that are feasible, but need to be validated in a pilot training system. For example, two years ago Link Division of the Singer Company, and the TransWorld Airline Training Center completed a joint experimental program for recording trainee performance. Software was developed for automatically recording all significant parameters (and other parameters considered interesting but not critical to performance) on three of the 12 maneuvers required for upgrading pilots to a new aircraft. Programmed comparisons and error scores were output. The results indicated that such programs were feasible, workable, and useful.

In a more recent project, Link delivered to the United States Armed Forces a "Synthetic Flight Training System" (SFTS) for use at the U.S. Army Aviation School.

The SFTS was designed for the Army's helicopter training program. It is a flight simulator that is a "generation" in advance of any current simulator in use for commercial or military training. Simulators other than the SFTS are basically instructor-controlled devices; i.e., the instructor sets-up the training problem and the flight environment being simulated and monitors the trainee, while he practices to develop the required skills.

In the SFTS, the computer rather than instructor can be made responsible for:

1. Selecting the flight problem - what the trainee will do in a particular training session,

2. briefing the trainee on the training problem to be executed,

3. demonstrating the ideal performance to the trainee,

4. scoring and evaluating trainee's performance against objective standards, and,

5. providing feedback to the trainee concerning his performance.

The SFTS incorporates the latest developments in automated training techniques and digital computer technology and performs the above listed functions efficiently and objectively. The automated training features also make possible adaptive training, whereby task difficulty is modified by manipulating selected variables, and making incremental additions and deletions of control inputs, and/or helicopter stability augmentation.

Like existing simulators, the SFTS also provides high fidelity simulation of motion cues, aural cues, cockpit instrumentation, and cockpit controls to provide a realistic environment for the training of pilot tasks. When fully implemented, it is anticipated that the SFTS will substantially reduce flying time in the Army's helicopter training program.

SUMMARY

Modern ground-based flight simulators have evolved, in part, from rapid development of increased computer capabilities. These same computer capabilities can, by innovative software development, be used to reduce the workload of the simulator instructor. Some of the major areas in which assistance can be provided are: (1) Rapid initialization for specific maneuvers; (2) automated demonstrations; (3) preprograming of a sequence of maneuvers; (4) automated malfunction insertion; (5) automated monitoring of procedural items; (6) recording of student performance; (7) automated performance comparisons; (8) providing knowledge of results; (9) adaptive training; and (10) providing a recording and playback capability for later study. In addition, other equipment capabilities have been developed for evaluation as to their application in a simulator pilot training complex. These include increased use of CRT display systems and automated briefings.

All of the features discussed are aimed at reducing the load of the instructor, thereby allowing him more time to function in the role of a manager of training and permitting him to concentrate on parameters which can only be handled by subjective evaluation. Such remaining activities are: (1) Diagnosis of problem areas resulting from a lack of student understanding; (2) identification of trends of incorrect performance across the total training spectrum; (3) identification of judgmental errors; and, (4) development of decision-making ability.

The combination of all the special training features, and the increased capability of the instructor to concentrate on required subjective evaluation areas, will result in maximizing the training value and efficiency of the simulator complex, thereby insuring a most cost-effective training program.

SIMPLIFYING DYNAMIC VISUAL DETECTION SIMULATIONS

DR. ROBERT C. SUGARMAN, Research Psychologist
and
MESSRS. HARRY B. HAMMILL, Research Physicist and
JEROME N. DEUTSCHMAN, Principal Engineer
Cornell Aeronautical Laboratory, Inc.

As part of a larger program at Cornell Aeronautical Laboratory, Inc. (CAL), it became necessary to use empirical data for the validation of a mathematical visual detection model, but more importantly to gain insight into the nature of visual detection of aircraft having a fragmented variation in brightness. The study of structured targets is of great interest because their detection cannot be validly derived by considering them to be equivalent to an unstructured target with uniform brightness equal to the average brightness of the structured target. Particular attention was paid to glint (specular reflection of the sun) and to brightness patterns caused by shadows cast by aircraft structures. Specifically, we were studying the detection of aircraft by ground observers. The required data were the instantaneous probabilities of visual detection of the aircraft at every point along its flight path.

In our search for such data, we found that previously reported laboratory studies used unpatterned (or unstructured) targets while field studies, using real aircraft, generally had poor documentation of the brightness variations of the target and the sky background. Hence, it was decided that a very basic experimental effort was needed. Essentially it consisted of the acquisition of data in the laboratory using human observers and simulated aircraft; and the subsequent use of the data to make quantitative comparisons within two families of structured targets with arbitrarily chosen parameters and to spot check the predictions obtained for the CAL visual detection model for unstructured targets.

Three possible experimental techniques were initially considered. They were: (1) Full-scale field tests using real aircraft; (2) scale-model field tests; and (3) laboratory tests. Considerations of both time and cost constraints, and experimental efficiency and controllability, required that the tests should be carried out in the laboratory. A technique was developed which did not require the presentation of moving stimuli, but rather required only the presentation of static targets for some length of time. The use of non-moving targets is predicated on the assumption that movement detection effects can be ignored since the range of the simulated aircraft is great at the time of detection.

The technique was based on a mathematical approach which requires as input, the average length of time spent in search to detect a target of a given size at each of several ranges, a search time limit, the number of times the target was detected within the search time limit, and the number of times the target was missed (search time limit was exceeded without detection).

From these data, the cumulative probability of detection may be calculated on the basis of an hypothesized target path and speed. The experimental methods used in this study bear a strong resemblance to one carried out by Krendel and Wodinsky in 1960, who simulated targets, by spots of light projected onto the dome in a planetarium (reference 2).

Rather than resort to slide projection of targets onto a standard projection screen in the present study, a large background screen was constructed against which physical targets could be presented. This provided several advantages over slide projection including: (a) A greatly increased field-of-view; (b) an increased viewing distance that allowed five observers to be tested simultaneously;(c) a greater range of brightness than could be provided with a photographic slide projector;(d) much higher screen brightness (this decreases the contribution of peripheral vision, relative to foveal vision, to a level closer to that for daylight brightness, and brings the brightness into the range where the brightness difference threshold ratio is independent of brightness); e) no "noise" as might be introduced by dust or scratches within the projector or on the film; and, f) relative ease of creating structured target locations.

METHOD. The procedure used in this experiment was the presentation of static targets, one at a time, on a relatively large background screen. Each target was exposed for thirty seconds, during which time the observers searched the background, with the goal of detecting the target in the shortest possible time. The targets varied in size, contrast, configuration, and location on the background. The experiment was conducted in the auditorium of the Cornell Aeronautical Laboratory. Heavy curtains on all windows provided control over ambient illumination.

BACKGROUND SCREEN. A vertical screen 8 feet high by 28 feet long, was constructed and located at one end of the auditorium. It was composed of seven 4x8 feet plywood sheets, each covered with a piece of 3/4-inch thick gray polyester foam. The shade of the foam allowed the targets to be composed of areas which were less reflective (darker) than the background as well as areas which were much more reflective (lighter) than the background. It was anticipated that each piece of foam would be uniform in color so that when the panels were juxtaposed they would appear as a single, seamless screen. In actuality, the edges of the pieces had nonuniformities which made it impossible to obliterate the dividing edges. The nonuniformities and the dividing edges were avoided in the selection of target locations. Three of the foam pieces differed by about 10% from the other four when their brightnesses were measured under the normal fluorescent room lighting. The screen may be seen in the background of figure 1.

ILLUMINATION. Although the brightness of the sky varies widely in magnitude, it is not practical to reproduce daylight brightness in the laboratory. It was possible, however, to provide sufficient illumination to insure that the background brightness was in the region where the brightness difference threshold ratio is equal to a constant. This illumination was provided by twelve 1000 watt lamps (G.E. Catalogue No. Q1000 PAR 64/7) placed 6 inches from the floor and about 20 feet from the screen. They provided a screen brightness that varied between 39.1 and 56.8 foot-lamberts over the screen. All brightness measurements were made with a Spectra Pritchard photometer. A panel covered with black cloth was placed at each side of the screen to absorb the illumination spillover from the lamps. A low barrier, also covered with black cloth, was placed between the lamps and the observers in such a position that the observers could see neither the lamps nor the floor between the lamps and the screen.

OBSERVERS' STATIONS. Five observers participated in the experiment simultaneously. Six barriers were arranged so that the five observers could sit in a row, facing the screen, without being able to see each other or the experimenters. Each station was 3 feet wide resulting in a distance of 6 feet between the midline of each end observer to the midline of the center observer.

During every observation period, each observer rested his head on a post 42.5 inches high, to insure that the eye height was uniform among subjects. Each of these head rests was located 50 feet from the screen. A curtain was hung across the front of the barriers which could be lowered between trials to prevent the observers from seeing the placement of the targets. With the curtain in the raised position, the observers could not see the area about the screen. The observers stations are shown in figures 1 and 2.

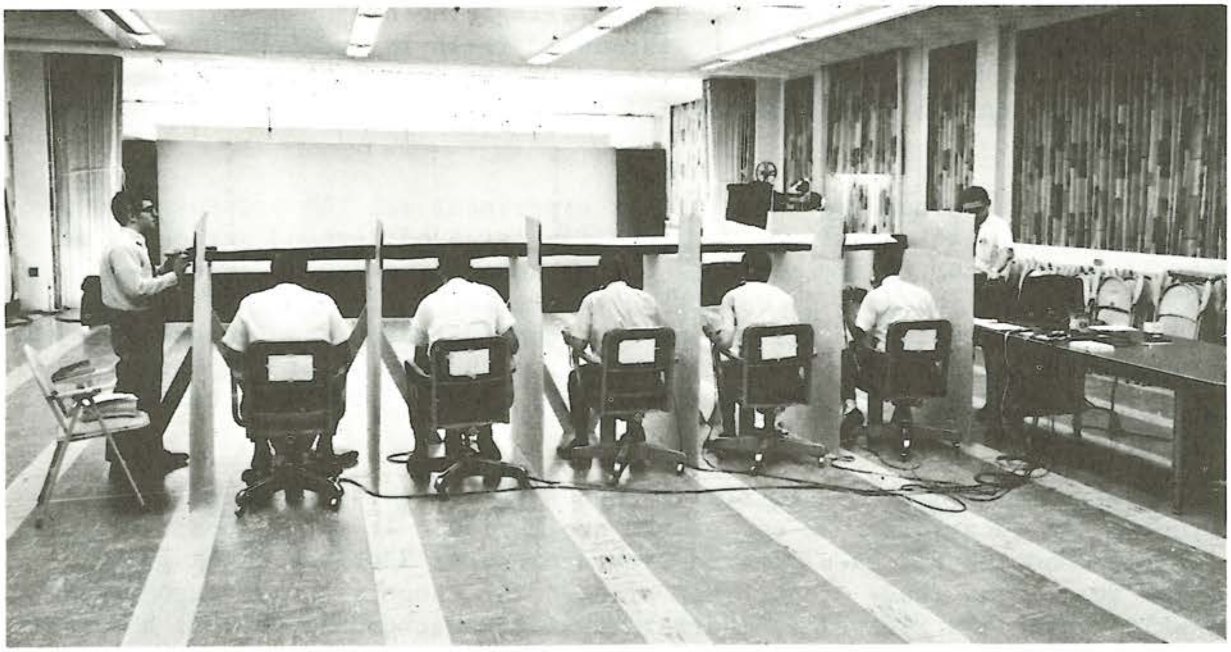


Figure 1. Experimental Arrangement Looking Toward the Screen

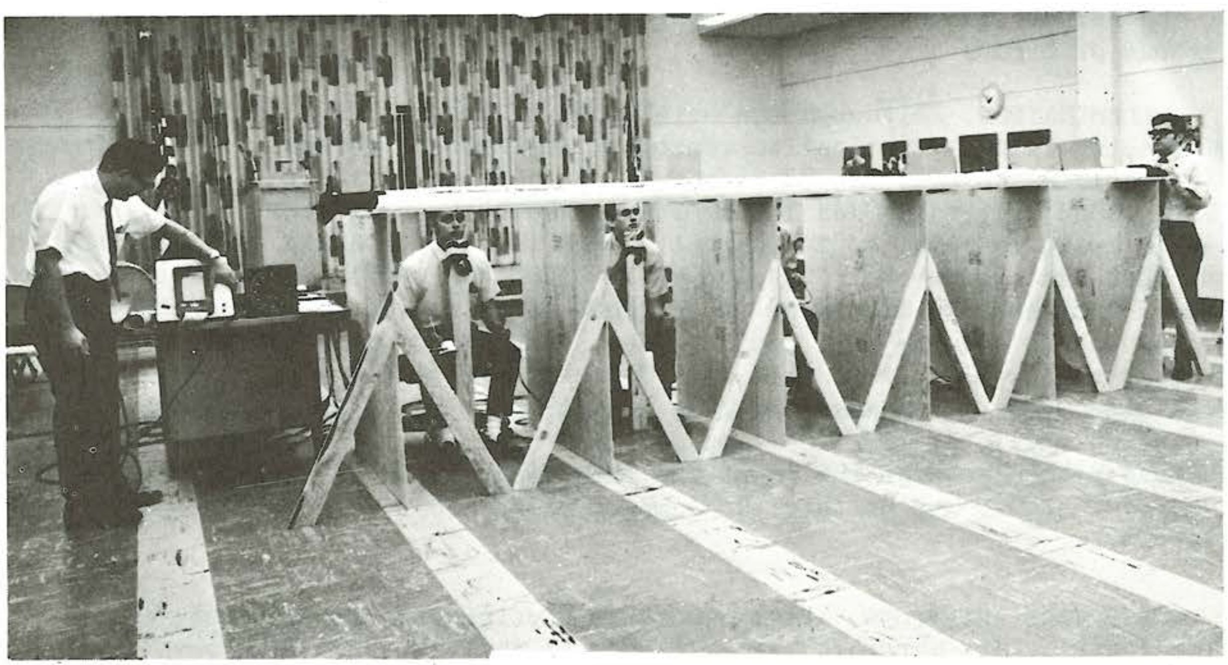


Figure 2. Experimental Arrangement Looking Toward the Observers

DATA RECORDING. Each observer held a push button switch which when pressed would activate a channel of a Brush 30-channel Operations Monitor (event recorder). A Gralab Universal Timer was connected, by way of a relay, to activate a sixth channel of the recorder whenever the timer was in operation. Each observer had a supply of scoring sheets on which was a line drawing of the screen, as shown in figure 3. The observers used these sheets to indicate the location of the target for each trial.

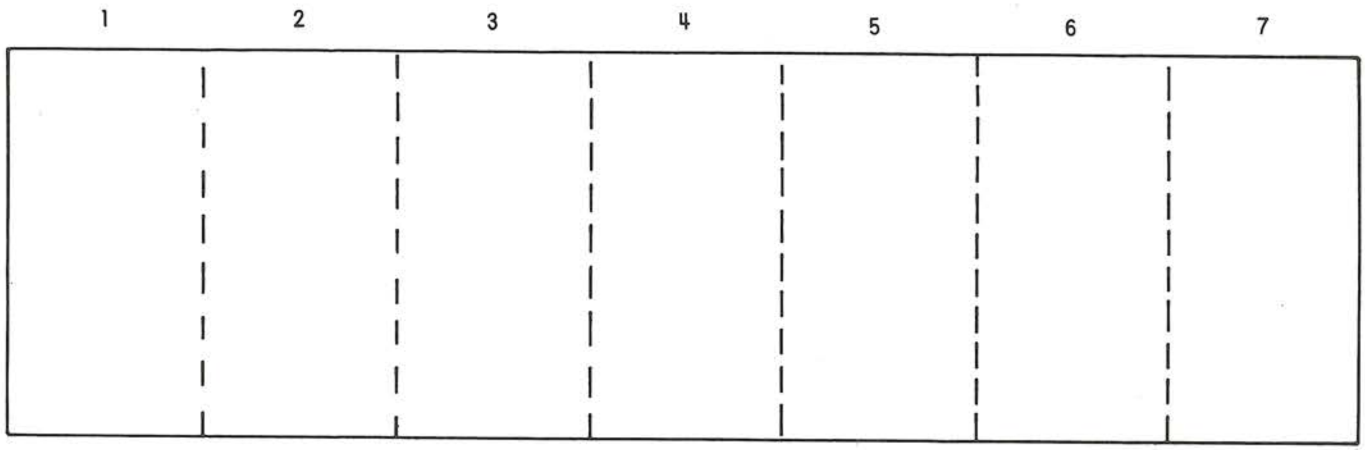


Figure 3. Sample Score Sheet used by Subjects to Indicate the Location of the Target

TARGETS. Six target configurations were used in the two studies performed; three were of uniform contrast, and three were structured. All targets consisted of, or were derived from, cut-out circles of varying shades of gray art paper. These papers were chosen for their matte surface as well as their particular contrasts with respect to the foam background. The papers were numbers G15 and 204 (Craftint Colormatch) and number Gray 8 (Color-aid). A piece of "double-stick" tape was attached to each target making it possible for the targets to be attached to the foam background and yet be easily removed by touching only the edges. Because of their thinness, the targets cast no shadows.

Contrasts of the three papers with respect to the background (as defined by $B_T - B_b / B_b$, where B_T = brightness of the target and B_b = brightness of the background) were measured for a variety of locations on the background and from the positions of various observers. For paper 204, the contrast varied between -0.47 and -0.56 with an average value of -0.51. For G15, the contrast variation was somewhat larger, ranging between +0.31 and +0.50, with an average value of +0.41. Paper number 8 also had a higher range of contrasts, varying between -0.10 and -0.23 with an average of -0.14. The contrast variability increased with increasing contrast. In one configuration to simulate glint, white spots were added to the targets. The spots were painted on the number 204 paper using Liquid Paper typing correction fluid which, was measured to be 11.5 times more reflecting than the foam background, and has excellent diffusing properties.

Figure 4 illustrates the basic configurations. The details of the six target configurations are given as follows:

1. Uniform contrast (-0.51). Circular targets were cut from paper number 204. Figure 4(a).

2. Uniform contrast (-0.14). Circular targets were cut from paper number 8. Figure 4(a).

3. Uniform contrast (+0.41). Circular targets were cut from paper number G15. Figure 4(a).

4. Glint. Targets of the first configuration were altered by adding three white spots. The diameter of each spot was 0.122 times the diameter of the target so that the average brightness of the target was equal to the brightness of the background (an average contrast of zero). As shown in figure 4(b), the spots were arranged in an equilateral triangle with the distance between the spot and the center of the target equal to two-thirds of the radius.

5. Structured (unbalanced). Targets of the first configuration (Figure 4(a)) were altered by cutting wedges from them leaving x-shaped targets (Figure 4(c)). The width of the bars equals 0.22 times the diameter of the circle from which it was cut. This results in the remaining area of the target equaling one-half of the original area of the circle, thus reducing the average contrast to -0.25. This target is illustrated in figure 4(c).

6. Structured (balanced). Targets as in figure 4(c) were attached to circles of equal diameter cut from paper number G15 (figure 4(d)). It had been anticipated that paper G15 would yield an average contrast of +0.5 so that the lighter areas of this target would exactly balance the darker areas for an average brightness equal to the foam (average contrast equal to zero). However, with the actual value of +0.41 for paper G15, the resultant average contrast was -0.05.

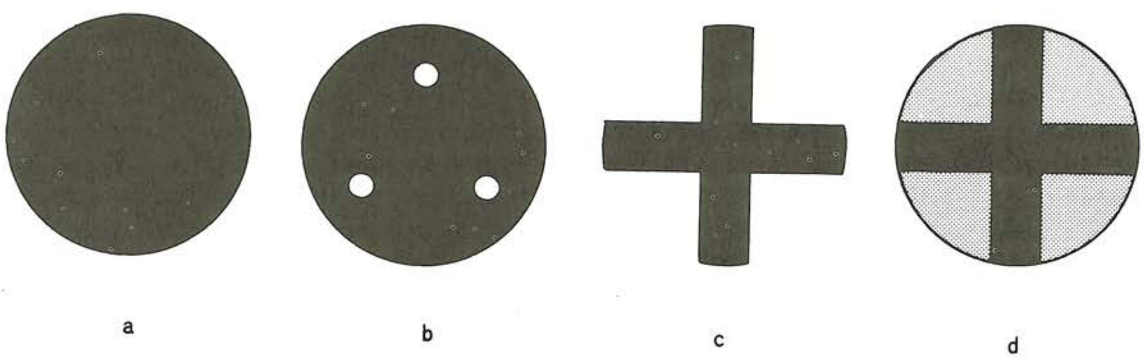


Figure 4. Basic Configurations: (a) Uniform Contrast Target; (b) Glint Target with Three Compensating Spots of Combined Area Equal To Five Percent of the Background Area; (c) Structured (Unbalanced) with One-Half the Area Removed; (d) Structured (Balanced) with One-Half the Area Compensating the Remainder

Each target configuration was presented to the observers in five different sizes. The sizes were selected on the basis of preliminary observations so that the largest sizes would be easily detected, while the smallest sizes would be nearly undetectable using foveal vision. This selection resulted in a different set of sizes for each target configuration. Table 1 lists the actual target size, as well as their angular visual subtense.

Subjects. Five male employees of CAL were selected from volunteers on the basis of having no worse than 20/20 vision as measured with a standard eye chart (Snellen) without correction. As far as can be determined, they were uninformed with respect to the hypotheses being tested, but probably were familiar with the general program.

TABLE 1. TARGET DIMENSIONS

CONFIGURATION	SIZE (DIAMETER) LINEAR (IN mm) 1	2	3	4	5	VISUAL SUBTENSE (IN MINUTES) AT A DISTANCE OF 50 ft 1	2	3	4	5
UNIFORM (-0.51)	5	8	9.5	15	25	1.13	1.80	2.14	3.38	5.64
UNIFORM (-0.14)	20	25	30	35	40	4.51	5.64	6.76	7.89	9.02
UNIFORM (+0.41)	5	8	15	25	35	1.13	1.80	3.38	5.64	7.89
GLINT	9.5	15	20	30	35	2.14	3.38	4.51	6.76	7.89
STRUCTURED (UNBALANCED)	9.5	15	20	25	35	2.14	3.38	4.51	5.64	7.89
STRUCTURED (BALANCED)	15	20	25	30	35	3.38	4.51	5.64	6.76	7.89

Procedure. Each trial consisted of thirty-second search period followed by another thirty seconds during which the observers' reports were gathered, and the next trial was prepared. Three experimenters were required to conduct the study.

The initial preparation consisted of the following steps and instructions:

1. The observers were familiarized with the general nature of the study.

2. The observers adjusted the heights of their chairs so that they could comfortably place their chins on their headrests.

3. The screen was exposed so that the subjects could familiarize themselves with its nonuniformities. The areas where targets would not appear (discussed below) were pointed out.

4. The set of targets to be used in a phase of testing were shown to the observers before the beginning of each phase. The targets were attached to the background and each was pointed out in turn.

5. The observers were informed that the targets would appear randomly (in position, size, and configuration) and that in approximately one-ninth of the trials no target would be used.

6. Observers were encouraged to search in as nearly a random fashion as possible; that is, they were to try to not systematically search in a fixed pattern.

7. In order to maximize correct responses and minimize false alarms, the observers were awarded points according to a payoff matrix in which correct responses (hits and correct rejections) were given one point, while wrong responses (misses and false alarms) were given zero points. The observers were informed that prizes of value from $10 to $2.50 would be awarded on the basis of total score, weighted by their average time to make a response.

Before the curtain was raised to commence a trial, a ready signal was given, at which time the observers were to take hold of their pushbutton switches and position their heads on the headrests. As the curtain was raised, the timer was activated which began a trace on the event recorder. As soon as each observer detected a target, he pressed his switch (for at least three seconds), which indicated his response on his channel of the recorder. If an observer did not detect a target, he was to let the time run out without pressing his switch. Immediately after indicating his detection of a target, the observer marked the position of the target on his score sheet. Second choices were forbidden. Unmarked score sheets were turned in when a target was not detected.

At the end of thirty seconds, the timer activated a buzzer and ended the timing trace on the recorder. The observers were then given immediate feedback by either pointing to the location of the target or informing them that no target was present. The curtain was then lowered. During the following half-minute, or so, the next target was placed on the background, and the score sheets were collected from each observer.

About 12 practice trials were given at the beginning of each day's session. They were chosen to constitute a random selection, but with at least one "no-target" trial.

EXPERIMENTAL DESIGN. The experiment was carried out in two phases. In Phase One, the targets used were Uniform Contrast (-0.51), Glint, Structured (unbalanced), and Structured (balanced). A complete sequence of trials was carried out on day 1. On day 2, the same targets were employed, but in a partially counterbalanced (as described below) sequence. In Phase Two, only the uniform targets (-0.51, -0.14, +0.41) were used. The Phase Two sequence was carried out on day 3 (a second sequence was not conducted).

In Phase One, there were 20 combinations of target configuration and target size. For purposes of assigning locations, the background was conceptually divided into three areas (right, center, and left) and then into four horizontal strips, for a total of 12 strips. Figure 5 shows the dimensions and positions of the strips. It may be noted that the left, right, and top borders were not used for target placement. This resulted in a search field 28° high and 8° wide. The strips were further subdivided horizontally and vertically to achieve a fairly uniform distribution of target locations.

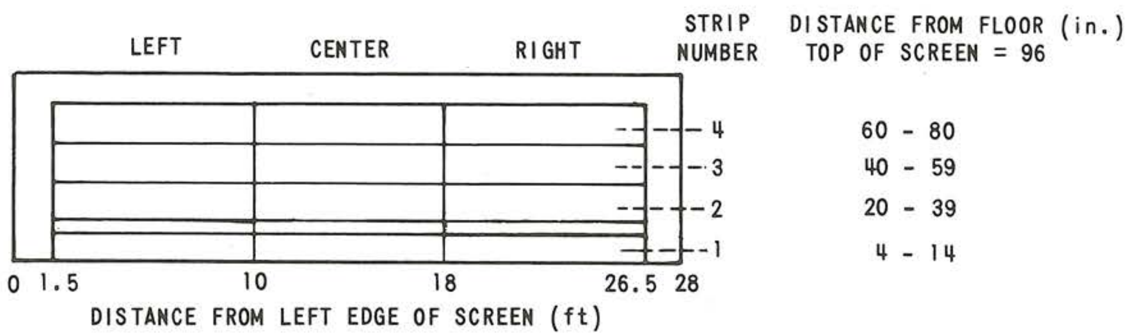


Figure 5. Dimensions and Locations of Screen Subdivisions

Horizontally the areas were marked off at one-foot intervals. Vertically each strip was subdivided into three positions for a total of twelve possible vertical positions. The height of the bottom strips was reduced in order to keep all targets presented there close to the bottom border of the background (hence the unused space between the first and second strips). This was done in order to look for possible effects caused by the presence of a "horizon."

All combinations of target size and configuration appeared once in each of the 12 area by strip (3x4) combinations. This required 240 trials (20x12). An additional 30 trials were randomly interspersed in which no targets were presented. On day 2, the sequence was run in reverse and with a partial mirror image of target locations.

A similar design was used in Phase Two, however, only 180 trials with targets were required since the number of target configurations was reduced to three (3x5) x (3x4). After the addition of 23 no-target trials, the total for Phase Two was 203 trials.

RESULTS AND DISCUSSION

FALSE ALARM AND HIT RATES. Table 2 gives the number of incorrect detections (false alarms) for each subject and for each day of testing including those trials in which a target was present. It may be seen that this type of error was very infrequent during Phase One (days 1 and 2), being less than 1 percent of the total possible false alarms. The false alarm rate increased to over 2 percent during Phase Two. This increase may be attributed to the use of more difficult targets. Almost one-half of these errors were made by observer 2. Considering only those trials in which no target was present, the average false alarm rate for Phase One was 1.7 percent and for Phase Two was 3.5 percent.

TABLE 2. FALSE ALARM AND HIT RATES

FALSE ALARMS (DETECTION OF A TARGET THAT DOES NOT EXIST)

		SUBJECT							
		1	2	3	4	5	AVERAGE	MAXIMUM POSSIBLE	FALSE ALARM RATE (%)
PHASE 1	DAY 1	0	5	1	1	2	1.8	270	0.7
	DAY 2	0	3	1	0	2	1.2	270	0.4
PHASE 2	DAY 3	3	9	4	4	3	4.6	230	2.3
AVERAGE		1	5.7	2	1.7	2.3			

HITS (DETECTION OF A TARGET WHEN IT IS PRESENT)

		SUBJECT							
		1	2	3	4	5	AVERAGE	MAXIMUM POSSIBLE	HIT RATE (%)
PHASE 1	DAY 1	198	201	217	207	174	199	240	83
	DAY 2	202	203	209	211	184	202	240	84
PHASE 2	DAY 3	130	133	140	139	128	134	180	74
AVERAGE		177	179	189	186	162			

The hit rates (correct detections) are also presented in table 2. As with the false alarm rate, the hit performance was similar on both days of Phase One; the greater difficulty of Phase Two was reflected in the lower hit rate for that data.

These results indicate the high reliability of the data, and that the nonhomogeneities in the screen (e.g., the edges of the panels) did not significantly contribute to the detection process. The latter is shown by the very low false alarm rate.

DETECTION PROBABILITY PER UNIT TIME (D) AS A FUNCTION OF TARGET SUBTENSE ANGLE (α). Figures 6 and 7 show the relation between D and α. D is a quantity defined so that the product of D and the average glimpse time is equal to the average single glimpse detection probability (see appendix). Alpha (α) is the diameter of the target in minutes. The data in figure 6 are combined in the following way:

1. The curve for the Uniform (-0.51) target series is the average of the two sets of runs (day 1 and day 2) from Phase One and the Phase Two data for the target.

2. The curves for the Structured (unbalanced), Structured (balanced), and Glint target are averaged for days 1 and 2 of Phase One.

The data in figure 7 include:

1. The average curves for Uniform (-0.51) taken from figure 6.

2. The curves for Uniform (+0.41) and Uniform (-0.14) as determined by the data of Phase Two.

The datum for α = 1.13 minutes on the curve for the +0.41 contrast was excluded since the value of D was zero.

The following observations may be made from the data in figure 6:

1. Clearly, the three structured targets decrease the probability of detection as compared to the Uniform (-0.51) targets. The Structured (balanced) condition yields much lower probability of detection than the Structured (unbalanced) and the Uniform (-0.51) condition.

2. There is no overlap of data for any curve with data of any other curve, indicating that the separations between the average curves for each treatment are reliable.

3. The curves for Uniform (-0.51) and Structured (unbalanced) are essentially parallel. If target shape is ignored, the Structured (unbalanced) targets may be considered to be the same as the Uniform (-0.51) targets but with half the area for the same maximum target dimension. In that case, there should be close agreement between the curve for Uniform (-0.51) and a curve derived by reducing the subtense angle of the Structured (unbalanced) by $1/\sqrt{2}$. Although not shown here, there is excellent agreement, especially at the higher values of α, verifying the independence of detection probability from shape for low height-to-width ratios.

4. The curve for the Structured (balanced) targets indicates a definite flattening (if not a decrease) at the higher values of α. A slight flattening may also be noted at the same place in the Glint curve.

5. The Structured (balanced) condition employed in the experiment yields lower detection probabilities as compared to the Glint configuration. Only two characteristics distinguish these two configurations from each other,

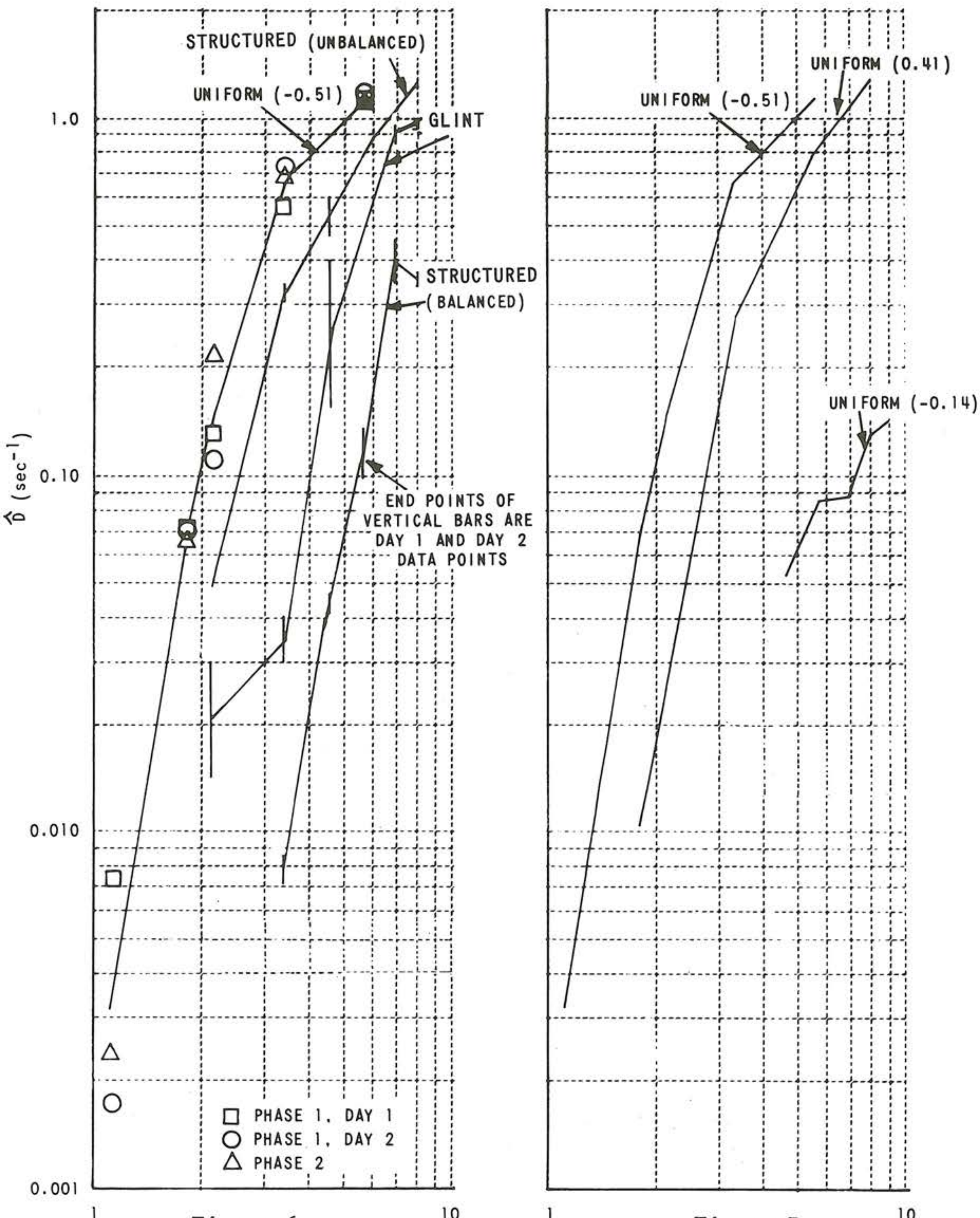


Figure 6 α (minutes)

Figure 7 α (minutes)

ESTIMATE OF D ($\hat{D}$) AS A FUNCTION OF TARGET SIZE (α)

and hence, one or both of the distinctions must account for the difference in performance. Those characteristics, dealing with the internal structure (patterning) of the targets, are:(a) The brightness variation (in magnitude) within the pattern of the Glint condition was greater than in the Structured (balanced); and,(b) the spatial pattern of the Structured (balanced) was more disjoint (broken up) than was the spatial pattern of the Glint target.

The factors affecting characteristics (a) and (b) include: The number, distribution, size, and perhaps shape of the bright areas. The metrics which relate the pattern characteristics (and their interactions) to detection performance are not known. Once theoretical and experimental programs are carried out to reveal these relationships, configurations as diverse as Glint and Structured patterns may be compared along common scales. Quantitative predictions may then be made regarding the probability of detection of structured targets.

The following observations may be made from the data in figure 7:

1. As would be expected, the detectability was best for the -0.51 contrast target and similar to the +0.41 contrast target with small differences between them. The -0.14 contrast target exhibited much poorer detectability than did the higher contrast targets. It must be remembered that the actual variation in contrast varied widely around the average of -0.14. The location performance curve is therefore tenuous. Predictions based on these data should be treated with caution.

2. The curves for the contrasts of +0.41 and -0.51 are essentially parallel. The curve for the contrast of -0.14 has a near-horizontal segment at an α value which is near that for a similar flattening in figure 6.

The origin is presently unknown for the flattened segments which appear in the D versus α curves of figure 6 (Glint and Structured (balanced) in the region of 7-8 minuts of arc), and figure 7 (Uniform (-0.14) in the region of 6 minutes of arc). It is assumed that these breaks in the curves are related to visual mechanisms since no procedural errors are known which could account for the effect. Further effort is required to establish both the "reality" of these breaks, and their sensitivity to the various stimulus parameters (i.e., α , c, target internal brightness variation).

Detection as a Function of Target Location. The data were analyzed in terms of the average detection time for each target (i.e., each configuration by size combination) at each of the 12 major screen subdivisions. Targets located at the center of the screen were detected sooner than targets located elsewhere. This may come about for two reasons: (1) The average angular distance between the fixation point and the target is less for central targets than for noncentral targets; and, (2) the observers might have used a fixation sequence which favored the center of the screen.

No consistent trend was found in the detection times to support the hypothesis that targets were most difficult to detect when presented at the "horizon." Experiments can and should be more specifically designed to further test this hypothesis.

Measured Search Behavior. Following the end of Phase Two, one observer was selected for further study to examine eye movements during search. He was instructed to search for a target on the background screen while instrumented with a Biosystems Eye Movement Monitor, Model SGH/V-2 (Biometrics, Inc.). The monitor recorded the horizontal movements of the eye with an accuracy of about one-half degree. No target was actually present during search. The output was recorded on a Sanborn chart recorder.

In the trace, which lasted 57 seconds, approximately 171 saccades (shifts of gaze) occurred. The number of saccades may be slightly more or less since movements, which were essentially vertical, produced only small horizontal signals. Consequently, those judgments were difficult to make. The result of the measurement was that on the average, the point of fixation was changed three times per second.

Furthermore, it was found that this observer began his search by quickly scanning the entire background screen. In the first 4.5 seconds, he scanned the full width four times. The full-field scans then slowed (more fixations per scan) to about three to four seconds. At about the twentieth second, he began a scan of the field which took 14 seconds to complete. After this, his scanning behavior seemed to duplicate his previous pattens (very fast scans, slowing to five seconds for the last scan of the entire field). This observer's search behavior was certainly not random, but neither was it following a rigorous pattern.

The most important finding of this search behavior study was that the glimpse time was measured to be one-third second. It is unlikely that the glimpse rate for the other four observers deviated significantly from this value, since previous laboratory results (Reference 3) have also reported a value of one-third second for the average glimpse time.

CONCLUDING STATEMENT

This analysis has dealt with the probability of detection for a single glimpse. The dynamic case (for aircraft changing in angular subtense, contrast, and position in the search field) may be calculated by use of the relationships derived in the appendix.

APPENDIX A

EXPERIMENTAL EFFORT AND MODEL RELATIONSHIPS

The purpose of this appendix is to establish the relationships between cumulative probability of detection, and the visual detection data generated within the experimental effort; i.e., to derive the probability of detection of moving aircraft from static target data. The approach philosophy is the replacement of the visual detection submodel in the present computer program with an appropriate statistical representation of the experimental data. In this way, cumulative probability of detection can be established for those target configurations in the experiment, particularly the brightness structured targets that cannot be handled by the visual detection submodel.

The material to be discussed is divided into three parts. The first part discusses a closed form expression for cumulative detection probability and relates this expression to the experimental effort; the second part establishes a statistical connection between D (probability of detection per unit time) and the detection data of the experiment, and the third part presents examples comparing data and the theoretical curve generated through use of an estimator of D obtained from the data.

<u>Closed Form Cumulative Detection Probability and Relationships</u>. Reference 1 has established for a continuous search a closed form expression for the cumulative probability of detection as a function of time, P(t), in terms of the instantaneous detection probability density,* D(t):

$$P(t) = 1 - e^{-\int_0^t D(t')\,dt'} \tag{1}$$

*Not a density in the sense of integrating to unity over the entire range of the argument t. D is a density in that it is probability per unit time, and that over a short duration τ, the detection probability would be given by $D(t)\,\tau$.

It is seen that the expression is sufficiently general to account for D varying with time during the search.

One application of Equation (1) is the computation of the cumulative detection probability of a ground observer searching for a penetrating aircraft. For this application, the time dependence of D is implicit through certain properties of the aircraft and search geometry:

$$\begin{aligned} D &= D(\alpha, C) \\ \alpha &= \alpha(t) \\ C &= C(t) \end{aligned} \tag{2}$$

where α is the apparent angular size of the aircraft and C is the apparent contrast. In the context of the present study, the apparent target contrast is considered to vary during penetration through the mechanism of contrast attenuation by the atmosphere, and the subtense angle α is determined as a function of time simply from geometry. It only remains to establish D (α,C) to apply Equation (1) to the problem of aircraft penetration.

In the experiment, the dependence of D on α and C was found by employing direct measurements of detection times for a series of specific α, C values and an appropriate data reduction procedure. With regard to the experiment, a stimulus of specific α and C was presented for search, and the times required for detection were recorded for a large number of independent trials. The connection between these times and the specific values of D for each stimulus is found by applying Equation (1) with D time-invariant during search:

$$P(t) = 1 - e^{-Dt} \tag{3}$$

where the value of D depends on α and C.

Maximum Likelihood Estimator For D. The maximum likelihood estimator is a widely used statistic and will be adopted here for the probability per unit time, D. The experimental data consists of an array of detection times for each target configuration and size. The elements of each array are replications (for a particular value of D) and can be considered independent samples of a random process. In addition to the actual detection times, there were also a number of misses within the allotted search time.

We can represent the data set by the multi-dimensional sample variable T in terms of N detection times and M misses:

$$T = \begin{cases} t_1, t_2 \ldots t_N \\ M \text{ misses} \end{cases} \quad (\text{for each target}) \tag{4}$$

By a maximum likelihood estimate we mean the most probable value of D in light of everything we know about the process. That is, we shall use for an estimate of D the value ($\hat{D}$) that maximizes the a posteriori probability density $p(D/T)$;* the solution of:

$$\frac{\partial p(D|T)}{\partial D} = 0 \tag{5}$$

for the observed data set T.

Prior to solving Equation (5) for D, it is necessary to establish $p(D/T)$. This can be done in the following manner:

By means of Bayes' Theorem $p(D/T)$ can be expressed:

$$p(D|T) \propto p(T|D)\, p(D) \tag{6}$$

where $p(D)$ is the prior probability density of D and where the proportionality constant of Equation (6) is independent of D. Since we have no established belief prior to knowledge of the data as to the value of D, $p(D)$ is taken to be constant over the range of D within which $p(D/T)$ is active. Thus Equation (6) becomes:

$$p(D|T) \propto p(T|D) \tag{7}$$

Since the N+M components of the sample T are independent, $p(T/D)$ can be written as a product of the individual probabilities. Therefore, $p(D/T)$ can be finally expressed:

$$p(D|T) \propto \left[P(t > t_0 | D)\right]^M \prod_{i=1}^{N} p(t_i | D) \tag{8}$$

where t_0 is the search time limit. The probability density $p(t/D)$ is found by differentiating Equation (3) remembering that D is independent of time:

$$p(t|D) = De^{-Dt} \tag{9}$$

Integration of Equation (9) from t_0 to infinity yields $P(t > t_0|D)$:

$$P(t > t_0 | D) = e^{-Dt_0} \tag{10}$$

From Equations (9) and (10), Equation (8) becomes

$$p(D|T) \propto D^N e^{-D\left(\sum_{i=1}^{N} t_i + Mt_0\right)} \tag{11}$$

---

* The Bayesian approach to maximum likelihood. As will be seen, the local extremum given by Equation (5) is in fact the global maximum for the specific case being considered.

which can be written:

$$p(D|T) \propto D^N e^{-D(N\bar{t} + Mt_o)} \tag{12}$$

where $\bar{t}$ is the average of the N detection times. Since the proportionality constant of Equation (12) is independent of D, the right-hand side of Equation (12) can be substituted directly for p (D/T) in Equation (5). Carrying out the differentiation and solving for D yields the maximum likelihood estimator:

$$\hat{D} = \frac{N}{N\bar{t} + Mt_o} \tag{13}$$

Examples of Cumulative Detection Probability. Figure 8 shows two examples of detection data and the corresponding cumulative curve. The search was truncated at 30 seconds (t_o) after initiation. The N detection times were ordered by numerical value and assigned ordinate values progressively larger by 1/N+M. The theoretical curves represent Equation (3) with D(t) replaced by $\hat{D}$ (Equation (13)).

ACKNOWLEDGEMENT

This work was sponsored by the Air Force Avionics Laboratory of the Air Force Systems Command, Wright-Patterson Air Force Base, Ohio; under Contract No. F33615-68-C-1319.

REFERENCES

1. Koopman, B.O. "Search and Screening." Operations Evaluation Group, Office of the Chief of Naval Operations, Navy Department, OEG Report No. 56, 1946.

2. Krendel, E.S. and Wodinsky, J. "Visual Search in Unstructured Fields." Proceedings of a Symposium National Academy of Sciences, National Research Council, Washington, D.C., Publication 712, 1960.

3. White, C.T. and Ford, A. "Ocular Activity in Visual Search." Visual Search Techniques, Proceedings of a Symposium, National Academy of Sciences, National Research Council, Washington, D.C., Publication 712, 1960.

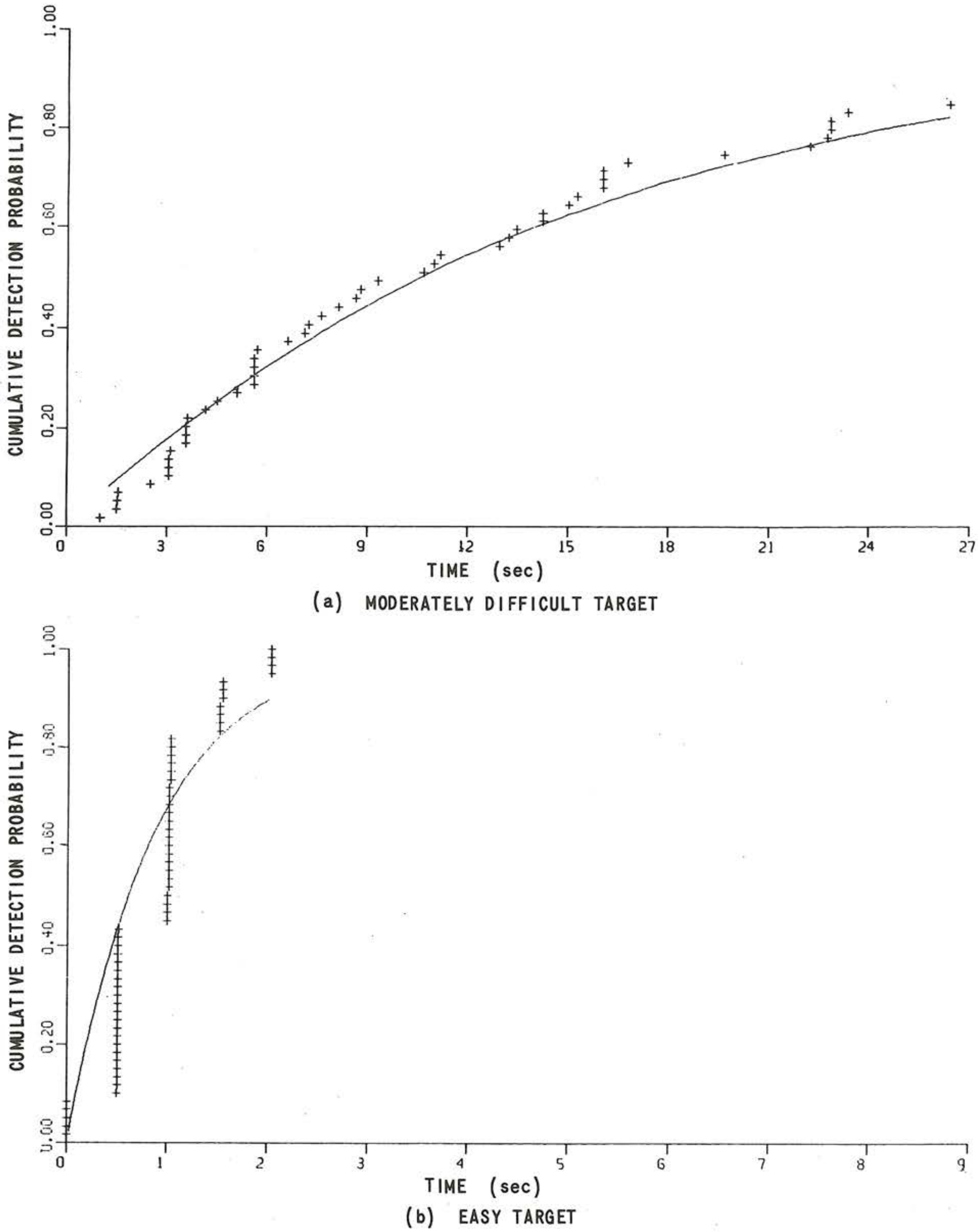


Figure 8. Examples of Data Fit to Theoretical Cumulative Probability (Note Scale Change in Time Coordinate)

VISUAL AND MOTION EFFECTS ON AN EXPERIMENTAL WIDE-ANGLE AIRCRAFT SIMULATOR

MR. E. SWIATOSZ
Visual Simulation Laboratory
Naval Training Device Center

INTRODUCTION

Traditionally the piloting of an aircraft was considered essentially a visual process. This is because the eye, coupled with the computational ability of the brain, provides the human with his most powerful sensor. Although much information is available on an individual area, such as visual, much of the information on the various sensory cues are fragmentary. (Cues being defined here as information which is useful to the operator in controlling a vehicle and in making decisions as to the state of the vehicle). It was due to the prohibitive and complicated nature of combining cues that little information had been obtained on the interaction of visual and motion cues in the control of aircraft. For this reason past motion system performance and pilot's vestibular reaction to motion were not adequately defined, nor fully understood. The early trainers were limited to attempts to create realism effects such as engine induced vibration or low intensity rough air. These movements were not correlated with pilot control, nor with the visual display. Hence, false or conflicting motion cues would be introduced with resulting negative training effects. One of the objectives of continuing research would be to consider techniques which would avoid conflicting or false cues imposed by the limitation of simulation equipment. However, as described in recent Human Factor reports,[1,2], the subject of the interaction of visual and motion cues is complex and difficult. This difficulty stems partly from the limitations of the hardware, but to a great extent it stems from the complexity of the human factor elements, and lack of information on their interactions.

HUMAN FACTOR PARAMETERS

The human factor elements(6) shown in figures 1, 2 and 3 indicate the visual and motion parameters which provide the sensory information. The visual parameters are given in figure 1 starting with solid angle from the subject's eye within which cues are contained. Brightness, resolution and contrast are not considered cues, but enable cue identification. Exit pupil defines the volume of space over which the displayed image may be viewed by an observer. Range of maneuverability incorporates ground area, altitude and rotational degrees of freedom. Registration and correlation refers to control action resulting in position, rate and acceleration. It also refers to the degree of specified accuracy for training device design. The Image Distance and Depth Cues are shown to consist of monocular and binocular cues. It should be noted that except for light and shade and accommodation (which refers to eye focussing) the monocular cues are amenable to quantitative or geometrical descriptions. The binocular cues are related to near distant cues such as for helicopter landings. Special effects refers to such things as variations in weather and visibility.

Proceeding further with figure 2 we can see some of the effects of various conditions on the threshold characteristics of a cue. These illustrate the effect of variables in detecting movement on a visual scene. Here we see

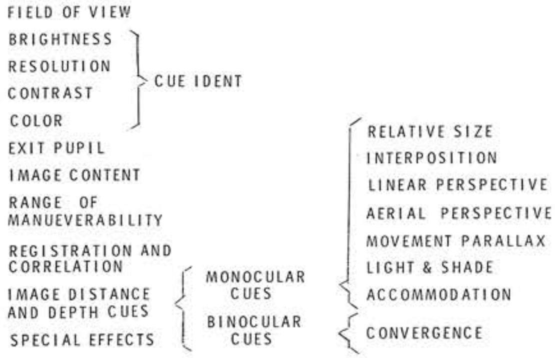


Figure 1. Visual Parameters

VARIABLE	FUNCTION	THRESHOLD EFFECT
VELOCITY	INCREASE	INCREASE
DURATION	INCREASE	DECREASE
FIELD	INCREASE	DECREASE
ILLUMINATION	INCREASE	DECREASE
RETINAL AREA	INCREASE PERIPHERY	INCREASE
ACUITY		
(MONOCULAR)	NEAR DISTANCE	INCREASE
(BINOCULAR)	NEAR DISTANCE	NO CHANGE

Figure 2. Variable Conditions Influencing Threshold Values for Discrimination of Movement

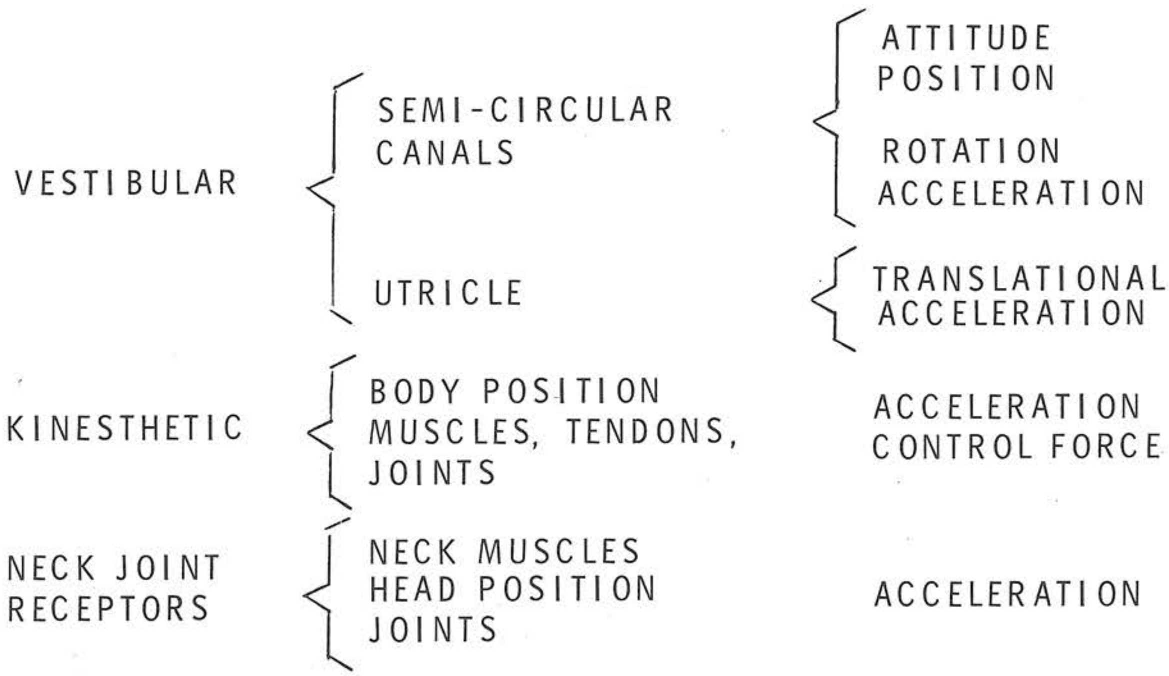


Figure 3. Motion Cues

that threshold increases for increases in velocity. An increase in duration of the visual scene lowers the threshold. Increasing the field-of-view or increasing illumination, decreases threshold (these two parameters are of particular interest because they are a vital consideration in effective utilization of the point light and wide-angle visual system in the NAVTRADEVCEN Visual Simulation Laboratory). The remaining are effects of the retinal area of the eye, and monocular or binocular condition at near distances.

In addition to the visual parameters, the motion and kinesthetic cues[2] to be considered are indicated in figure 3. These motion cues are essentially those of acceleration and changes in attitude or angular position. The principal source of motion sense is the vestibular apparatus which consists of two sets of sensors, one set located in each inner ear. Each set is composed of an angular sensor or semi-circular canal and a linear acceleration sensor called the utricle. The vestibular systems behaves as a stable platform which first, senses static and dynamic orientation of the head, and second, stabilizes the eye so that clear vision is possible in spite of head motions. The kinesthetic cues are derived by the operator from the movement of his limbs as he actuates his controls in the vehicle, or as the vehicle is exposed to changes in acceleration. The kinesthetic or control force cues and their important interaction, with the vestibular and visual sensors, have attracted interest only recently and little information has been published on it. Of even more recent interest are the neck muscles and head combination as a motion sensing apparatus.[1,2] These respond to acceleration with resulting changes in muscle tension as the supported head is moved and acts as a motion receptor. This, in turn, interacts with the vestibular system in a way that is also as yet not completely understood. These type of interactions appear to typify a new trend in which the combinations of sensory characteristics and simulator are considered as a unit rather then just the simulator by itself.

The classification of cues (whether they are primary, secondary conflicting or masking cues) depend on the responsive characteristics of the various sensors. For example, because of its frequency bandwidth characteristics the vestibular sensors have a faster response than the visual sensors. The kinesthetic control force cues produce even quicker responses. Because of this these sensors would be superior for the higher order motion of accelerations and rates of acceleration onset cues. The visual cues on the other hand are on the lower end of the frequency spectrum but are indispensable in detecting vehicle position and other predominantly visual cues.

As we will discuss later, some of the more recent techniques[4] for the combined motion and visual simulator will be to take advantage of the characteristic frequency bandwidth of the motion and visual sensors to simplify motion platform requirements. These will include electrical filtering and washout techniques for separating the visual and motion cues in accordance with their appropriate frequency bandwidth.

In these techniques the motion receptors of man are matched to the appropriate portion of his environment in order to avoid illusions in the form of disorientations or false perceptions. Illusions are related to the loss of visual reference, however, a major contribution to disorientations occurs in those situations where frequancies of the motion environment are lower than those of the sensor frequency spectrum. Thus, for example, the semi-circular canals would be incapable of detecting a very slow roll error. If the pilot corrects his error rapidly and the original roll was not perceived, the pilot is forced to assume he has rolled in the opposite direction when, in fact, he is straight and level. Thus, in general, illusions may occur due to large motion excursions or slow continuous turns with prolonged mis-alignment with the inertial gravity vector. These illusions can take the form of diving when recovering from a turn, sensing a wrong tilt when in a skid, a nose high attitude during takeoff, and other illusions involving inversions, spirals, and spins.

Effects of motion sickness were reported with NTDC Device 2FH2, a fixed base cockpit and point light source wide-angle visual screen. Similar effects were reported on recent tests sponsored by the U.S. Army Aviation Material Laboratory on the Northrup wide angle point light source visual system. This particular system similar to the one with NAVTRADEVCEN Visual Simulation Laboratory, has inherent dynamic visual distortions which are also a probable cause of motion sickness. However, when motion cues were added, the occurrence of motion sickness was reduced drastically. In these cases it was the experienced pilots who became sick, due to lack of motion, but not the new trainee. This apparently was an indication of the habit pattern in utilizing motion cues. These particular phenomena were the basis for the incorporation of a motion platform with the point light source visual display installed in the Visual Simulation Laboratory. Other factors which may cause motion sickness are the previously mentioned lack of motion fidelity and poor optical performance.

NAVTRADEVCEN VISUAL SIMULATION LABORATORY POINT LIGHT SOURCE EQUIPMENT

Considerable effort has gone into the development of the point light transparency systems since about 1960. They are, in theory, capable of simulating the view from an operator aerial position of a two or three dimensional ground terrain in correct perspective without the use of sophisticated electronic equipment. Basically, this technique uses a point light source of high brightness which casts the "shadow" of a photographic transparency onto the wide screen surrounding the operator as shown in figure 4. The transparency is mounted on a servo-driven gimbal system, which translates and rotates with respect to the stationary point light source, for all six degrees of freedom, and portrays the motion of the simulated vehicle on the screen.

The relative position of the point light source to the transparency is analogous to the position of the actual vehicle with respect to the ground. This can be seen from the diagram in figure 5 by taking the ratio of similar triangles, one formed by the subtended scene and the other by the image on the transparency. The simulated altitude dimension "h" is subsequently found to be equal to the distance "d" from the point light source to the transparency times the transparency scale factor. Thus, it is possible to vary the simulated altitude in direct proportion to changing the distance between the light source and the transparency. It is also possible to change the transparency and scale factor depending on the altitude and scene resolution requirements of the mission intended for simulation.

An example of a visual scene from a transparency having three-dimensional models of transparent buildings, various structures and trees mounted on it is shown in figure 6. A scale factor of 100 to 1 is used for this transparency which gives an acceptable resolution for 3-D perspective missions close to the ground. For greater ranges in altitude and maneuverability a two-dimensional

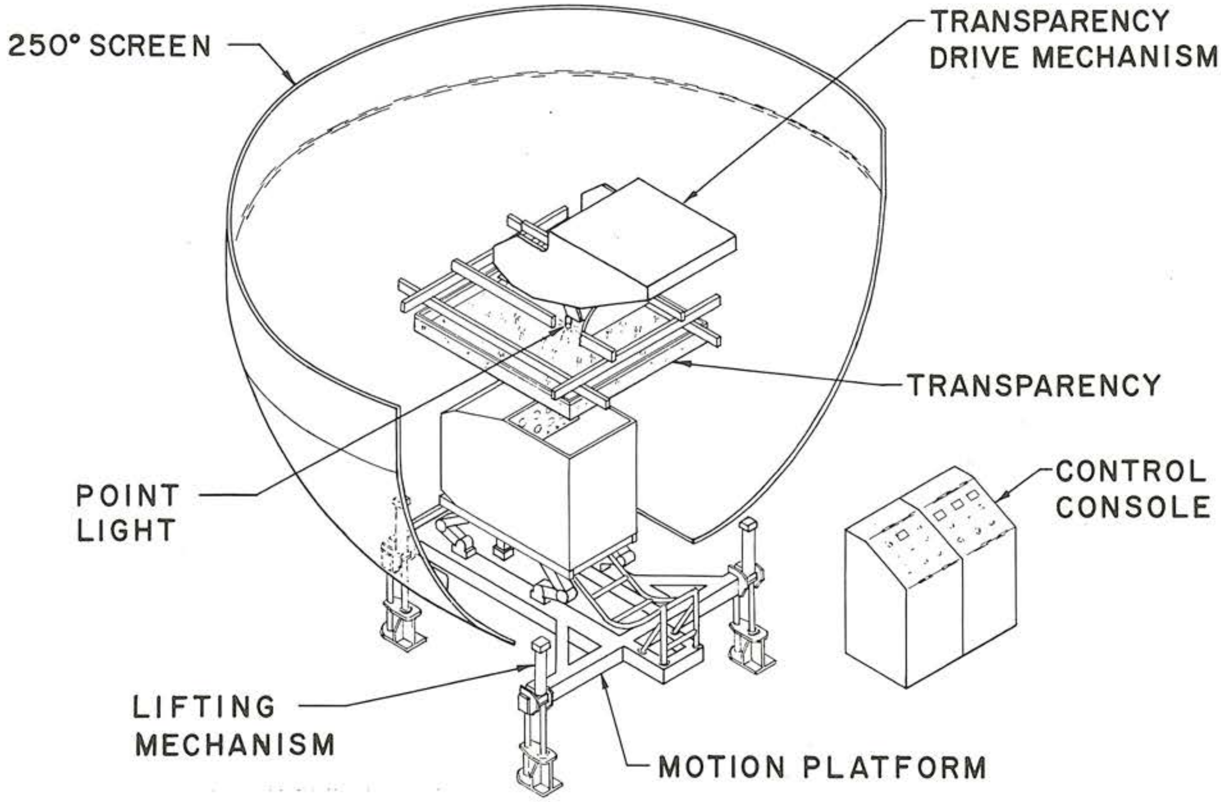


Figure 4. Point Light Source Visual System and Motion Platform

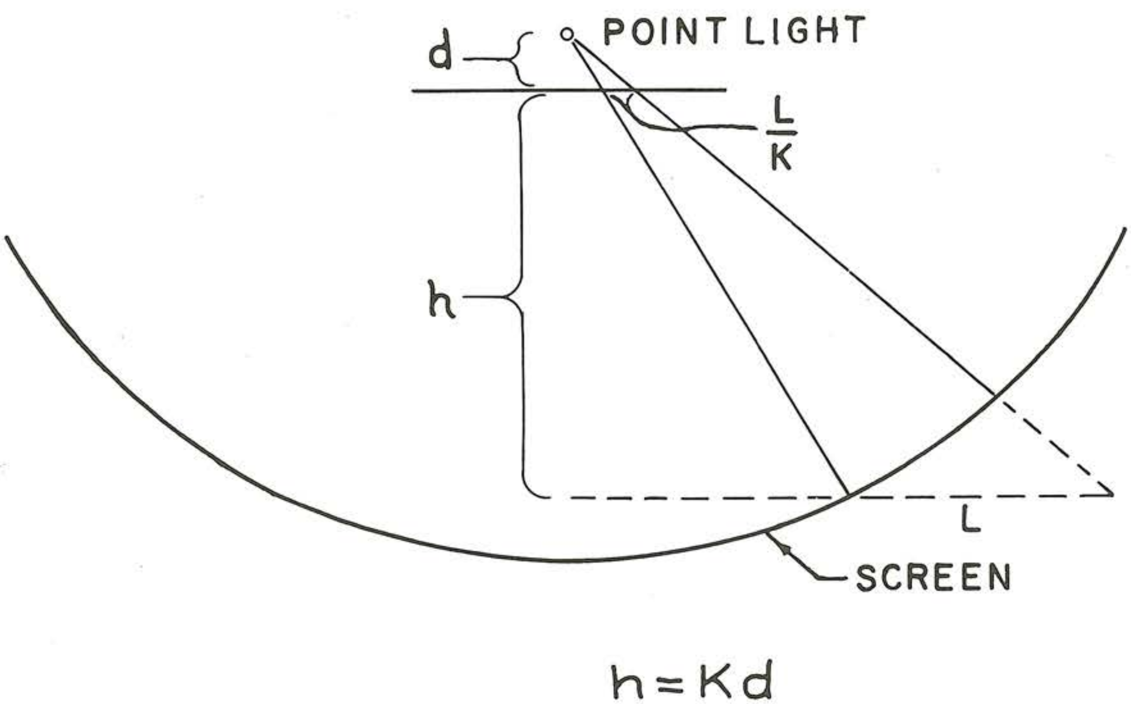


Figure 5. Point Light Source Scale Factor

Figure 6. NAVTRADEVCEN Devide 2-FH-2 Point Light Source Helicopter Trainer

transparency is used with scale factors up to 2500:1 or larger. The photo of the scene, as shown, appears distorted since the camera used for taking the photo was located a considerable distance from the point light source location.

The NAVTRADEVCEN Visual Simulation Laboratory equipment indicated in figure 5 includes a point light source, a 250° wide screen, several semi-photographic color, and black and white transparency, a transparency drive mechanism, the hydraulic motion platform, hydraulic power supply, which is not shown, and the control consoles and associated electrical equipment. The motion platform is a compact design and is mounted on a hydraulic lifting mechanism. Quick disconnects are used to break the hydraulic lines so that the motion platform can be lowered onto a dolly and easily transported to another location, where it can be used with the wide-angle TV projection, for a future assault boat motion simulation. The motion platform was originally constructed by the NAVTRADEVCEN Laboratory Services Department from a Melpar design for Device 2F75 for a helicopter simulation project.

The motion platform shown in figure 7 has capability for ±15° pitch, ±15° roll, and ±6" vertical translation. The motion platform features a booster actuator to balance out the static load. It also has an important feature - an adjustable point of rotation in pitch. This is important because the direction of pitch acceleration and the nature of the pitch motion cue is highly dependent on the point of rotation. This is accomplished by the combined actions of the two pitch and heave actuators, which can be pre-programmed to represent the point of rotation of the simulated aircraft. They also provide vertical translation when they operate in unison. The point of rotation in roll is fixed and it is independently actuated from pitch and heave.

IMAGE QUALITY PARAMETERS

The quality of the projected scene, which can affect operator performance, depends on the resolution, brightness, and distortion of the projected image. The most important factor affecting resolution is the size of the point light, which for the Visual Simulation Laboratory light source is about .004 of an inch diameter. Other factors affecting resolution are the photographic resolution of the transparency and the magnification or the distance between the light source and the transparency. The image brightness depends on the projection distance, screen gain characteristics, the point light optical system, and the total radiant energy of the light source.

The two parameters of resolution and brightness have limitations which are a characteristic of the point light source system. The distortion problems(3), however, are more general and would apply for any visual system where the observer's eye is displaced from the light source position. These consist of size, position, and velocity distortion.

As shown in figure 8, size distortion results, since the observer views the screen from a point, just below the transparency close to the point light source. The image, however, is not exact due to distortions which depend on geometrical relationship between the observer and the point light source

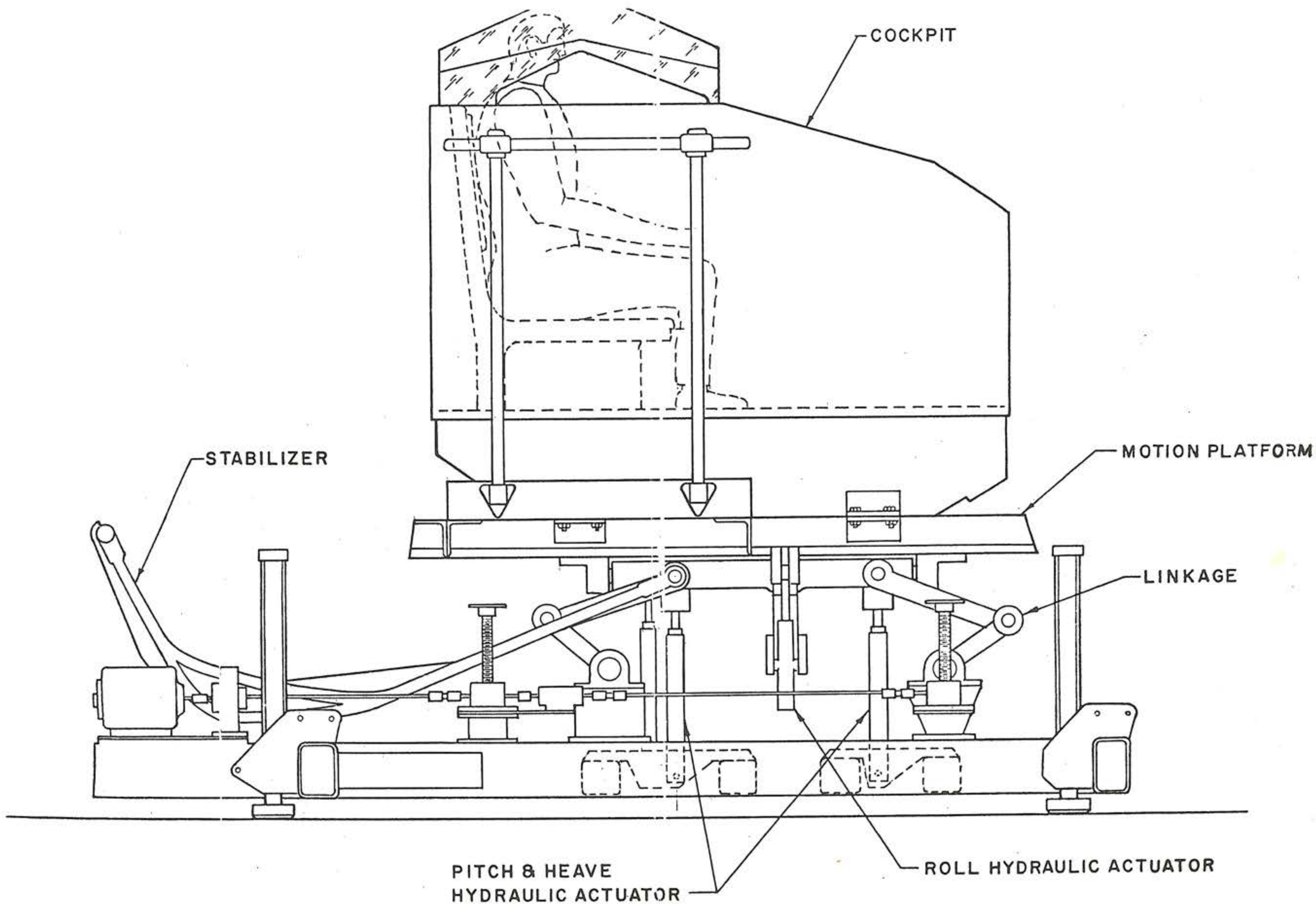
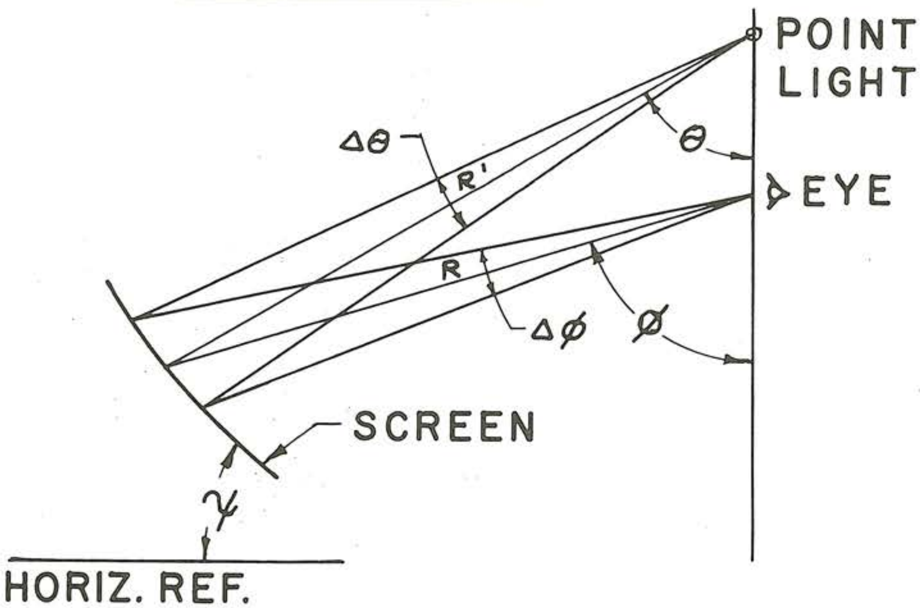


Figure 7. Motion Simulator

SIZE DISTORTION



$$S.D. = 100\left(\frac{\Delta\phi - \Delta\theta}{\Delta\theta}\right) = 100\left[\frac{R'\cos(\phi-\theta)}{R\cos(\theta-\psi)} - 1\right]$$

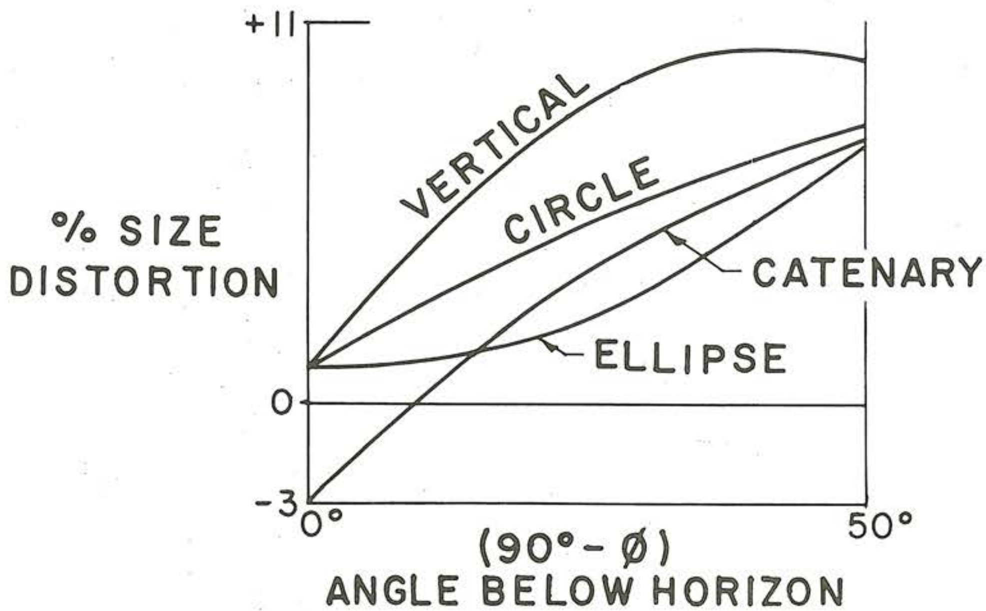


Figure 8. Image Quality Parameters, Size Distortion

as a function of the screen radius. This distortion is expressed as the ratio of the difference of the subtended angles and $\Delta\dot{\theta}$. From the curves for this expression, the catenary and the ellipse screen contours show the least size error. It will be shown later, however, that the ellipse has other disadvantages due to dynamic distortions. In general, the distortion in size of the projected image is primarily dependent on the slope angle of the screen surface and in most cases less dependent on the eye positions.

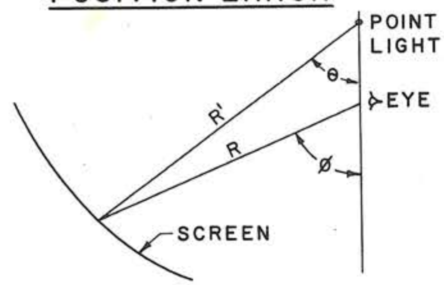
The error in the projected position, on the other hand, is a critical function of both the eye position and the screen shape as shown in figure 9. If the screen shape is such that the error in position varies across the screen, undesirable velocity and acceleration errors will occur. Since the eye is located below the point light, the image appears at a higher elevation than the true elevation. The horizon then appears to be above the observer resulting in the effect of traversing the inside of a bowl. The expression for position error can be obtained from simple geometry and is expressed as the difference between the angles ϕ and θ. We find the error is a maximum at 90^{o} from the vertical and minimum of zero error at 0^{o} from the vertical. This bowl effect is minimized by placing the projected horizon at eye level and using a separate sky projector.

A more serious error is the rate of change of the previous position error indicated in figure 10. This is the velocity error across the screen causing projected straight lines to bend or flex as the scene moves. The equation for the percent velocity error is obtained by taking the derivative of the position error and is shown as a function of the angle θ, the radius R and the rate of change of R with respect to θ and thus is a function of the shape of the screen.

The graph of velocity error is shown for circle, ellipse, vertical, and catinary cross section. The catinary curve appears the most attractive, since it doesn't show a rapid rate of change in velocity error across the field. In addition, the catinary was a very simple shape to construct by using sections of appropriate lengths of flexible sections of material whose distributed weight would generate the catinary curve. For these reasons this screen shape was selected for the Visual Simulation Laboratory.

With the imaging errors minimized to a satisfactory degree, the main problems remain with scene resolution and screen luminance. As shown in figure 11, only a portion of the light from the point light penetrates the transparency and the supporting plexiglass. The amount transmitted depends on the angle of incidence. Thus, the brightness varies across the screen with the highest brightness below about 40^{o} incident angle and then decreasing with partial light reflection until the light is totally reflected at about 85^{o} incident angle. This blackout occurs near the horizon and thus illumination for the sky and horizon is required through a separate sky projector. As will be shown later, this decrease in brightness is compensated by the increase in resolution due to the increase in range distance. Due to the variation of brightness across the screen a high gain specular screen such as aluminous paint could not be used. The screen used in the Visual Simulation Laboratory is a retro-reflective glass bead with a cloth backing, having a gain of about 2.6; the use of a retro-reflective screen tends to reflect more light back to the viewer in the cockpit and thus minimizes the detrimental effects of the off normal illumination. Screen brightness measurement from .1 to .3 foot lamberts were obtained with the

POSITION ERROR



POSITION ERROR; $\phi - \theta = \tan^{-1} \frac{d \sin \phi}{R + d \cos \phi}$

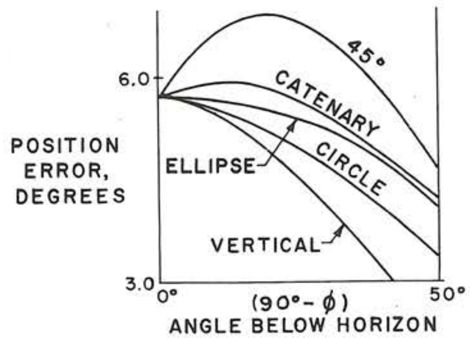
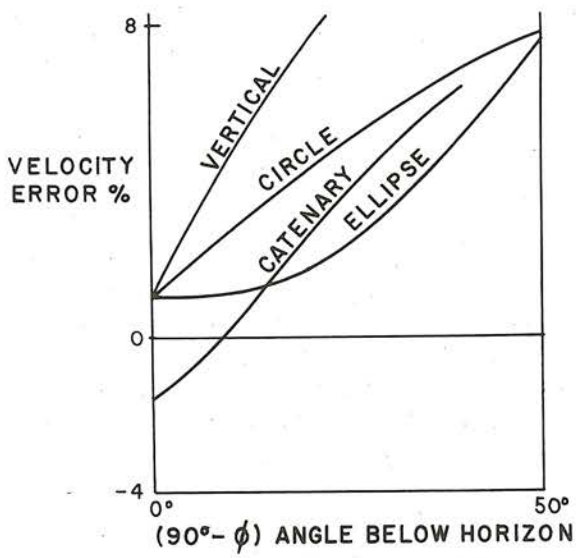


Figure 9. Image Quality Parameter
Position Error

VELOCITY ERROR



VELOCITY ERROR;

$$100 \left(\frac{\dot{\phi}}{\dot{\theta}} - 1 \right) = 100 \left[\cos \theta - \frac{dR}{d\theta} \cdot \frac{\sin \theta}{R} \right] \frac{1}{(R^2 - \sin^2 \theta)^{1/2}}$$

Figure 10. Image Quality Parameter
Velocity Error

TRANSMISSIVITY

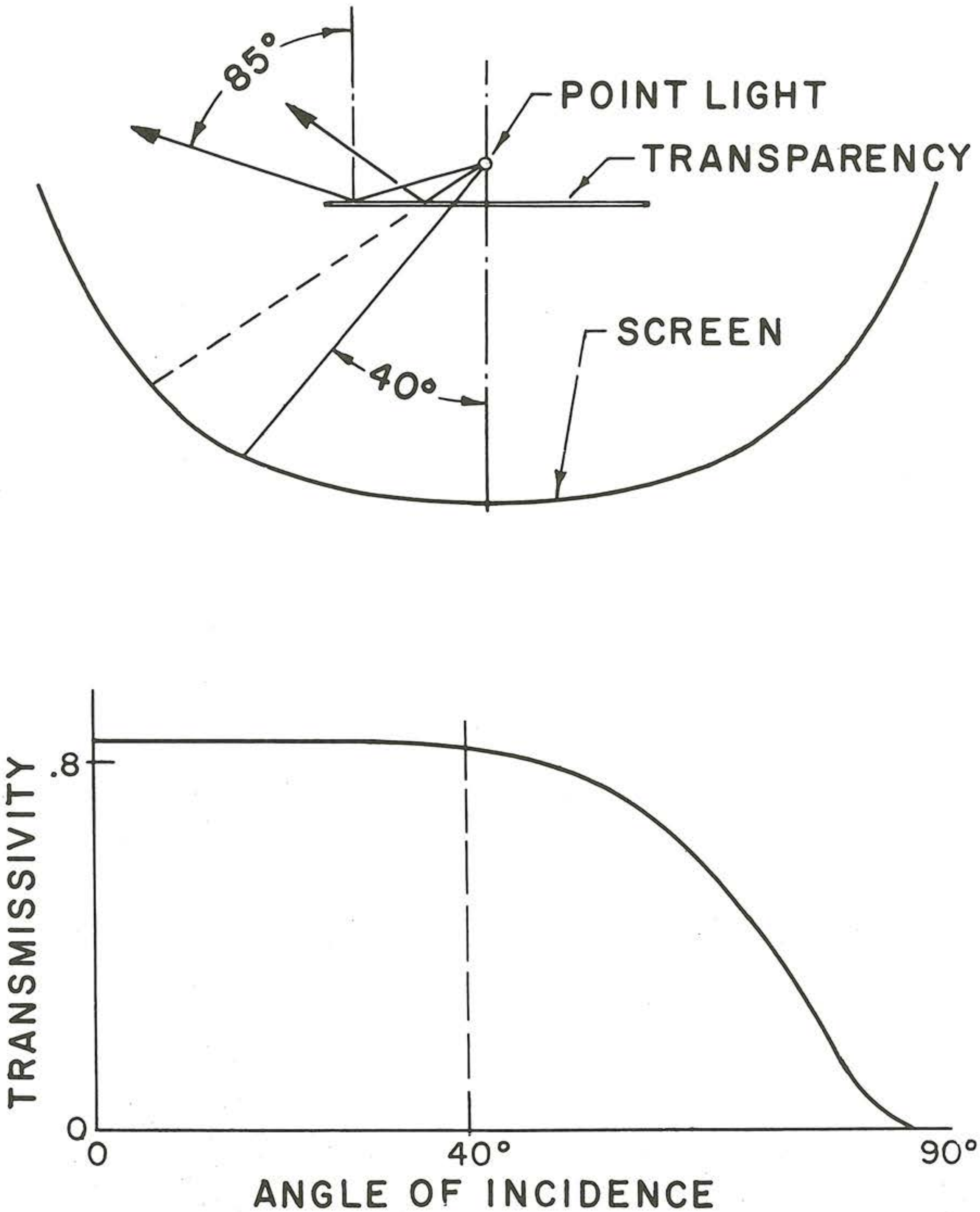


Figure 11. Image Quality Parameter
Transmissivity

laboratory equipment which is expected to be sufficient for the dark adapted eye for intended experimental purposes. The resolution of the point light source has been recently measured. It is shown in figure 12 to compare favorably to a television system at higher slant ranges. It can be seen that angular resolution for the point light system increases with a decreasing slant range. That is, the resolution deteriorates rapidly when the point light approaches the transparency or the slant range decreases below about 1/4 of its maximum. This is attributed to the effect of the size of the point light source on resolution. This also means that, when the transparency images are further away from the point light, the improvement in resolution compensates or offsets the previously mentioned loss of brightness with angle of incidence with the transparency. It is also noted that changing the transparency scale factor will shift the resolution curve. Thus, comparisons with other systems may require that these curves must be normalized to a common scale factor. It should be pointed out that the resolution indicated in figure 12 is available for the point light system with a greater wide angle capability than the television system.

MOTION PLATFORM REQUIREMENTS

Motion platforms in general, as stated earlier, cannot duplicate the translational motion of the aircraft exactly because of its limited motion capabilities. Thus, after an acceleration cue is sensed the motion must be washed out, that is it must be decelerated below the threshold of the operator's motion sensor before the platform reaches its limiting stops. If we consider the velocity of the Visual Simulation Laboratory motion platform during a uniform deceleration we see from figure 13 that it forms a parabolic envelope which is the limiting displacement of the motion platform cues. This envelope determines when the washout is to occur in accordance with what the velocity of the platform is at a certain position. The constant K would be selected so that the deceleration would be below the threshold that a person can detect. We can see from the curves for displacement, velocity and acceleration that the washout takes a considerable portion of the available distance. The washout is accomplished by using a switching circuit which is analogous to the platform motion equation. In this equation the constants K_1 equals 1 or zero so that when the platform is tracking the motion signals from the computer, $K_1 = 0$ and only the tracking terms remain. When the velocity reaches a value which corresponds to the position as determined by the washout envelope, K_1 then equals 1, and the first tracking term is cancelled leaving the washout term.

In the case of the pitch and roll for the normal landing type problems the attitude or angular cues could be represented fairly closely. For this reason the present Visual Simulation Laboratory configuration includes washout only for the heave or vertical translation direction. The roll cockpit motion will include provisions for side force cues and return to neutral during a coordinated turn. The visual display will provide all the remaining apparent translational motions including the vertical motion independent of the cockpit heave. The visual display will be stationary during the pitch mode with the cockpit providing the pitching cue. In the roll direction, the visual display will move relative to the cockpit to give a true apparent roll cue.

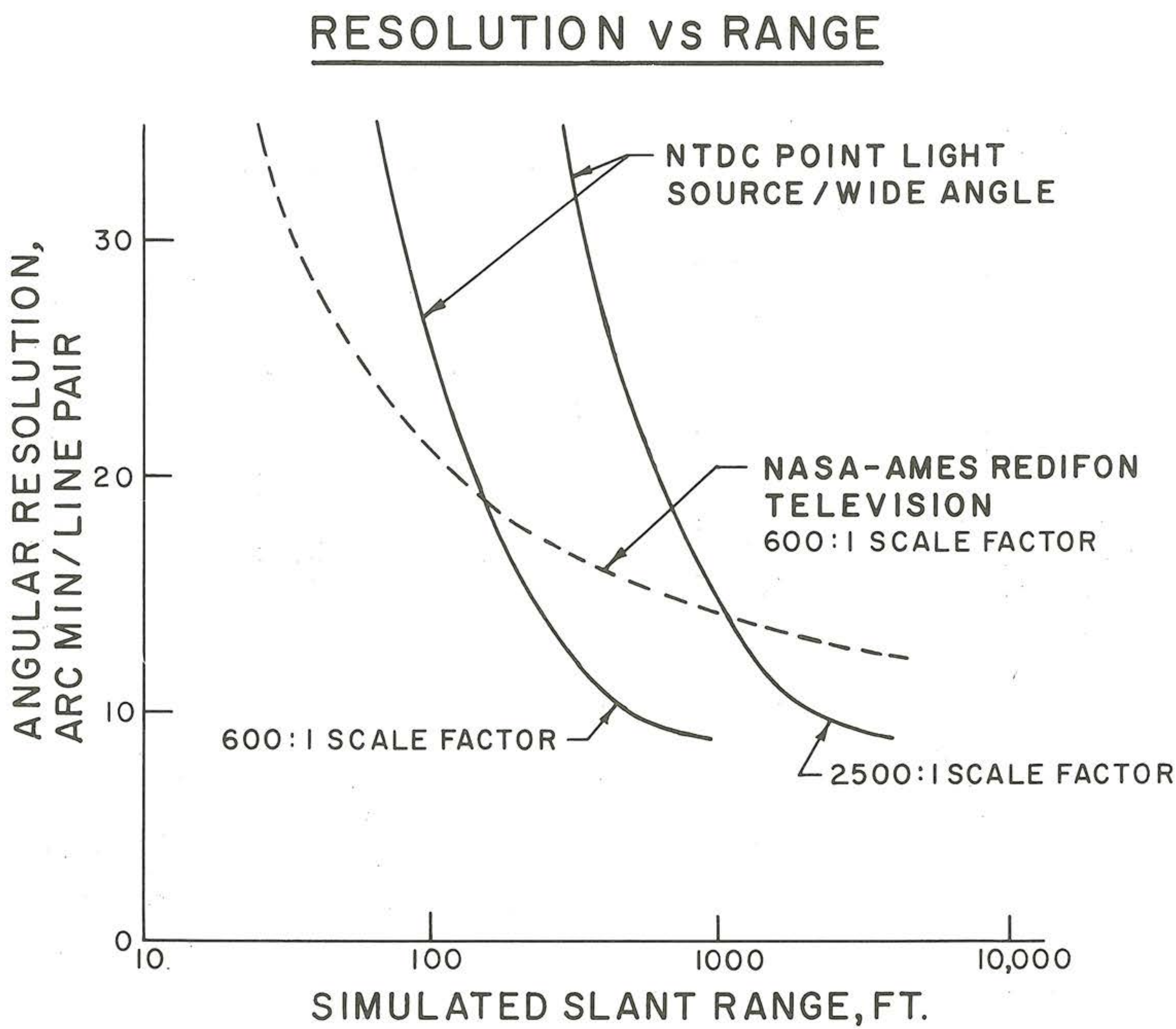
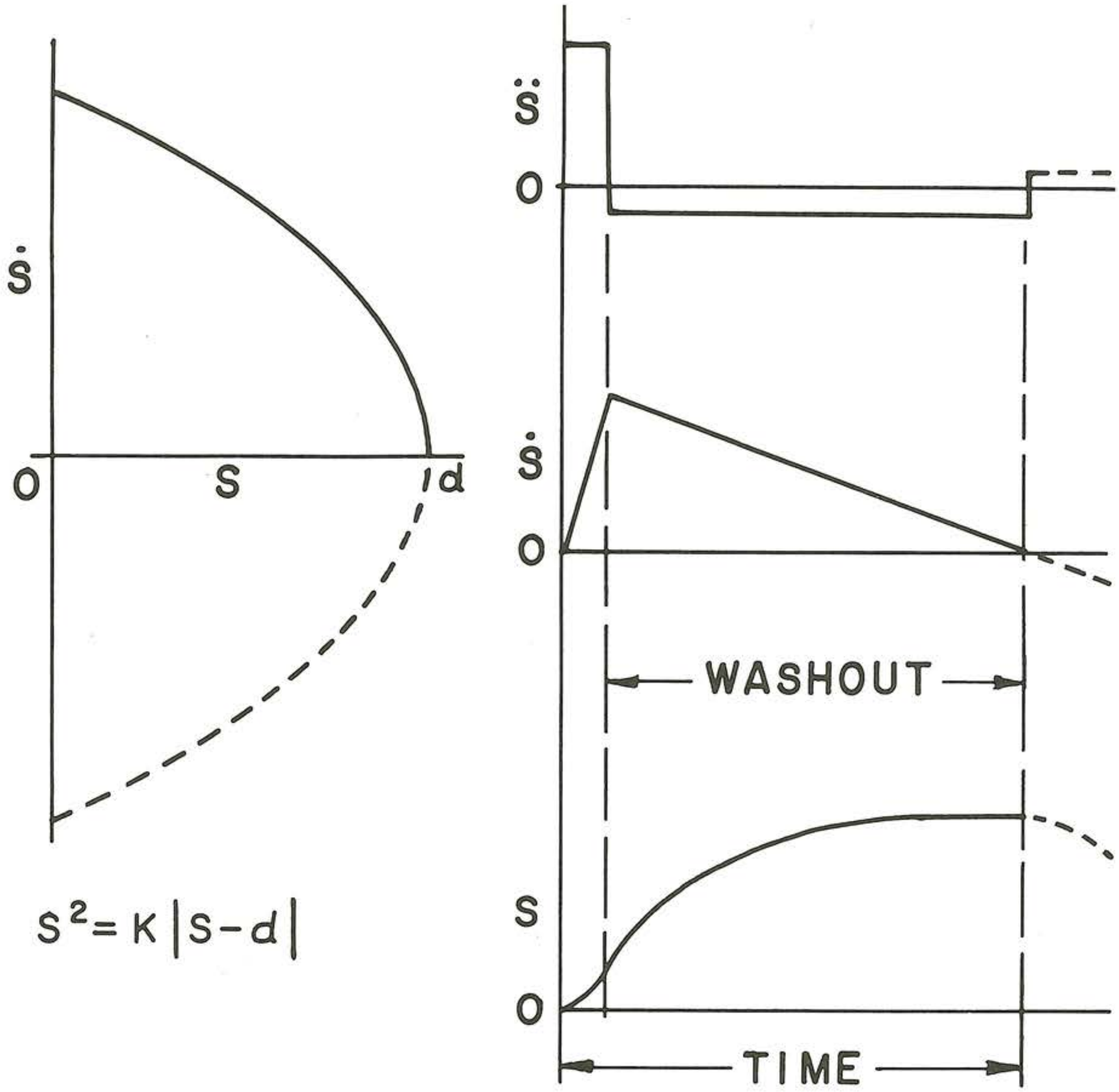


Figure 12. Image Quality Parameter
Resolution VS Range

MOTION CUES



$$\ddot{S} = K_1 \dot{q} - \dot{W}_G$$

$$S = \int \left[\dot{S} K_{sn} + K_1 \left(-\dot{S}_n + K_2 \sqrt{S'_n - d} \right) \right] dt$$

Figure 13. Motion Platform Requirements, Motion Cues

The roll displacement will be made to rotate as a function of roll rate. This is a satisfactory method to provide a quicker motion response to compensate for the lag of the equipment using only computer signals which represent the true motion. This also means that the platform will return to neutral position when the roll rate is zero and when the displacement signal gradually decays to zero by the roll circuitry. The separate visual system meanwhile continues the illusion of a roll attitude.

Figure 14 indicates the possible forces resulting from a turn. For a coordinated turn which would not have a skid or side slip, the gravity vector side component is balanced by the centrifugal force during the turn which accompanies roll. Hence, the platform displacement would be zero and the visual system would continue the illusion of roll. However, should the pilot maneuver result in a net side force as in an uncoordinated turn, then an additional motion cue for a prolonged steady state force is required. The technique here, as mentioned earlier, is to use the gravity vector to produce the side force by rolling the simulator to the appropriate side depending on whether the force is outward or inward and then depend on the dominance of a strong visual cue to overcome the angular sensing mechanism of the canals of the inner ear.

Thus, we see that the motion platform does not provide an exact duplication of the aircraft orientation as well as the motion due to inherent limitations of the motion platform. However, accurate cues are required and the combination of the cockpit motion and visual display must indicate an accurate orientation of the aircraft. For the roll direction, as shown in figure 15, the visual display must therefore move in such a way that the relative motion between the motion platform and the visual display motion system produces an apparent aircraft motion, as viewed by the operator in the cockpit. On this basis the platform equation of motion, as previously shown, combines with the true motion signals from the computer to determine the drive signals to be provided to the visual display.

RECENT VISUAL/MOTION TECHNIQUES

A relatively new technique[4] which is currently used on other point light visual and cockpit motion systems, and under consideration by the NTDC Visual Simulation Laboratory for future modification is illustrated on the block diagram of figure 16 for the roll and simulated lateral directions. This system uses a high pass filter as indicated by the transfer function to introduce the high frequency components to the motion platform. The low frequency components to the visual system are obtained by taking the difference between the computer displacement signals and the filtered high frequency signals. This is in accordance with the human factor requirements mentioned earlier where the frequencies below the motion sensor threshold is avoided for the motion platform. Thus, the time constant used in the transfer function is selected experimentally to match the human motion sensor. The filters also provide the required washout of the motion cue. Phase lead compensation is introduced to the motion and the visual system by adding the velocity signals to the displacement signals. As with the displacement signals the high frequency components of velocity signal are directed to the motion platform and the low frequencies to the visual system. The true apparent motion, as discussed previously, is obtained by maintaining the current relative motion between the visual system and the cockpit. The lateral accelerations are introduced through a low pass filter. This provides

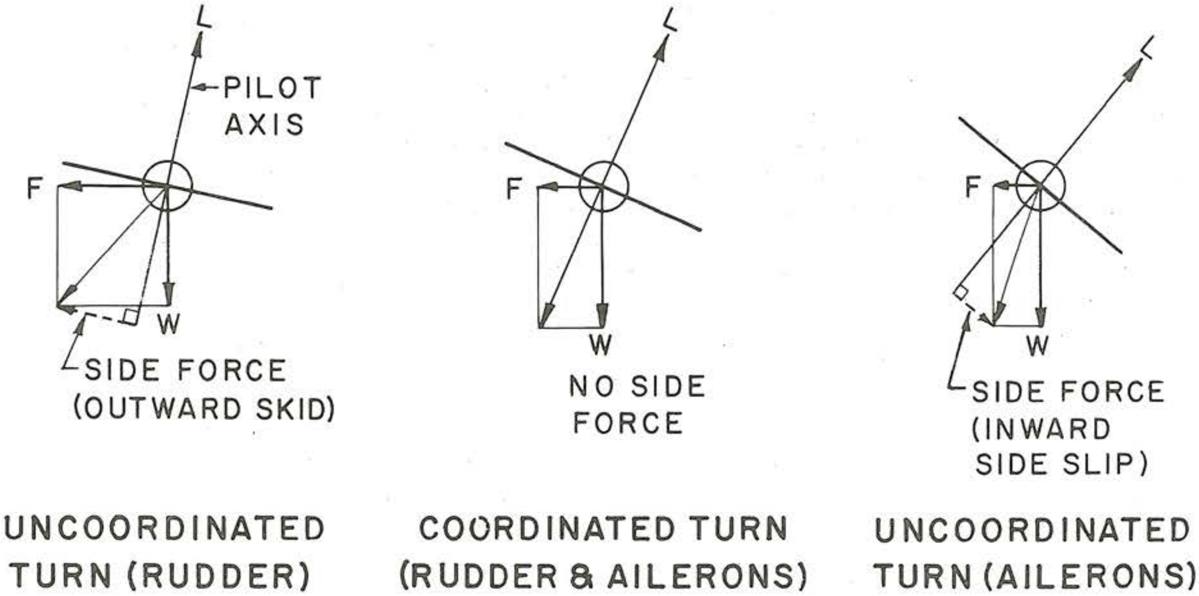
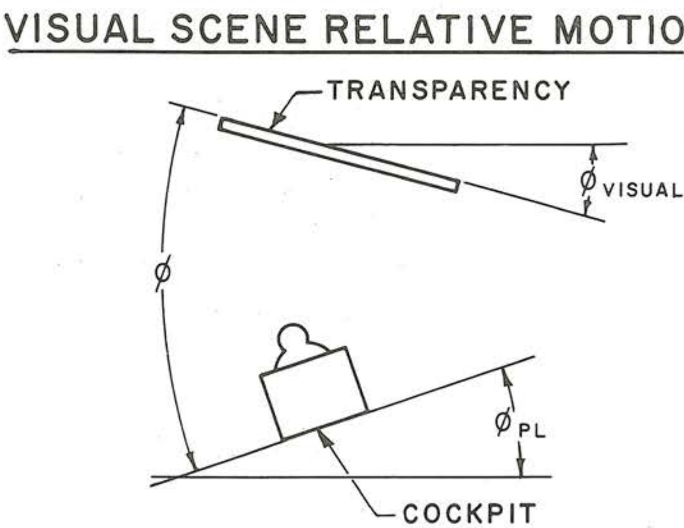


Figure 14. Pilot Turning Forces



$\phi_{PL} = \dot{\phi} + \theta + \lambda$

$\phi_{VISUAL} = -\phi_{PL} + \phi_{VISUAL/PL}$

WHERE $\phi_{VISUAL/PL} = \phi$

ϕ = COMPUTER SIGNAL (APPARENT DISPLACEMENT)

$\phi_{VISUAL} = K_1\phi - \dot{\phi} - \lambda$

Figure 15. Motion Platform Requirements
Roll Direction

LATERAL MOTION SYSTEM-VISUAL DISPLAY INTERFACE

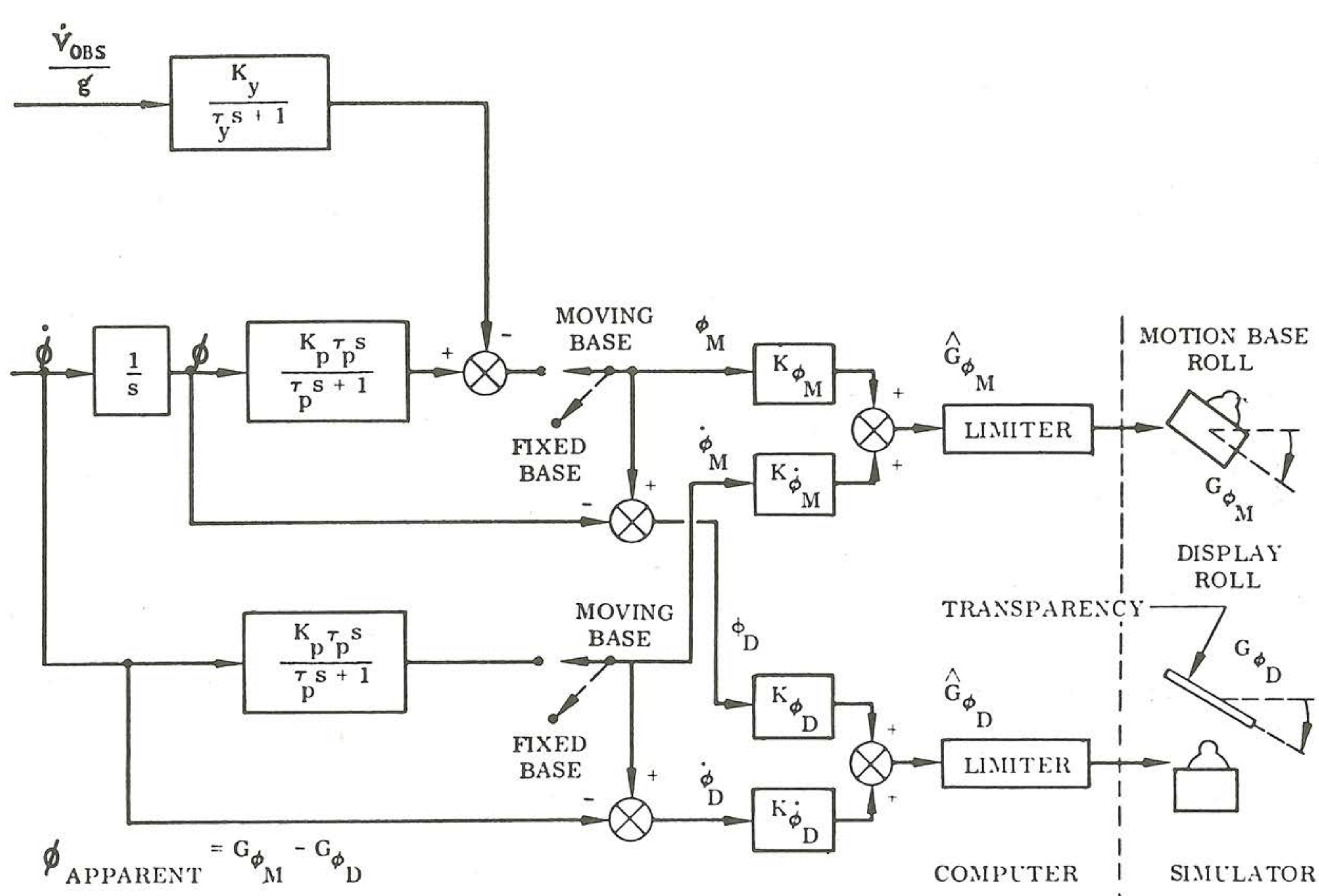


Figure 16. Block Diagram Recent Visual/Motion Techniques

a signal which will rotate the cockpit for a simulated side force by utilizing the gravity vector. In this case, the time constant is such that the high frequency components are filtered out so that the angular sensing ear canals are not affected, but the lower frequency linear utricle sensors will provide the prolonged acceleration effect during a side slip or a simulated uncoordinated aircraft turn.

COMBINING VISUAL AND MOTION SYSTEMS

In order to combine the motion and visual systems, the response characteristics of both the motion platform and the visual motion device must be matched to avoid visual distortions and false cues. Dynamic tests were performed on the NTDC Visual Simulation Laboratory equipment to determine the frequency response for both visual and motion systems. The results of these tests as shown in figure 17 indicated a drastic difference between the two systems for the pitch and roll directions. For example, as shown on the chart the 3 db cutoff for the visual basic motion device in roll was only .2 Hz while it is a respectable 1.1 Hz for the cockpit motion platform.

This unsatisfactory difference between the motion and visual system is shown again in figure 18 on the frequency response and phase lag curves for the roll direction. In an effort to make the two systems compatible, by making their phase lag vs frequency curves nearly identical, a study was made to determine the means to improve the roll and pitch visual system frequency response. This study indicated that the pressure drop in the 70 feet of pressure and return hydraulic lines from the hydraulic drive station to the transparency drive actuators were excessive and subsequent test data was obtained as shown on the next figure to verify the hypothesis.

If we compare the test data with slopes generated by the representative linear equation of motion as shown in figure 19, we see that the slope of $N = 1$ for the velocity exponent indicates that viscous portion of the curve dominates the loading. A slope of 2 for the inertia exponent is at a much higher frequency and therefore was not a dominant term. The hydraulic line size was subsequently increased which improved the frequency response by a factor of 4 from .2 Hz to .8 Hz. This would satisfy the requirement for the visual frequency bandwidth to match the bandwidth of the motion platform. Further electrical adjustments or compensation methods would be the next step to make a closer matching of the visual and motion drive systems.

An important point here is that the original specifications for the visual system would have been inadequate to meet the requirements for the present intended purpose of the equipment. That is, the maximum velocities and accelerations were specified and reported in the acceptance tests for the original equipment but the mechanical frequency considerations were neglected in the specifications.

As a recommendation, specifications for motion drive systems should include frequency response and phase lag information as well as a complete description of performance as shown on the nomograph in figure 20. The performance curve shown as an example is for the motion platform in the

ROLL	**± 15°**
PITCH	**± 15°**
HEAVE	**± 6 IN**
ACCELERATION	**± ½ G**
HYDRAULIC PSI	**800 OPERATIONAL**
	3000 TEST

Figure 17. Motion Platform Characteristics

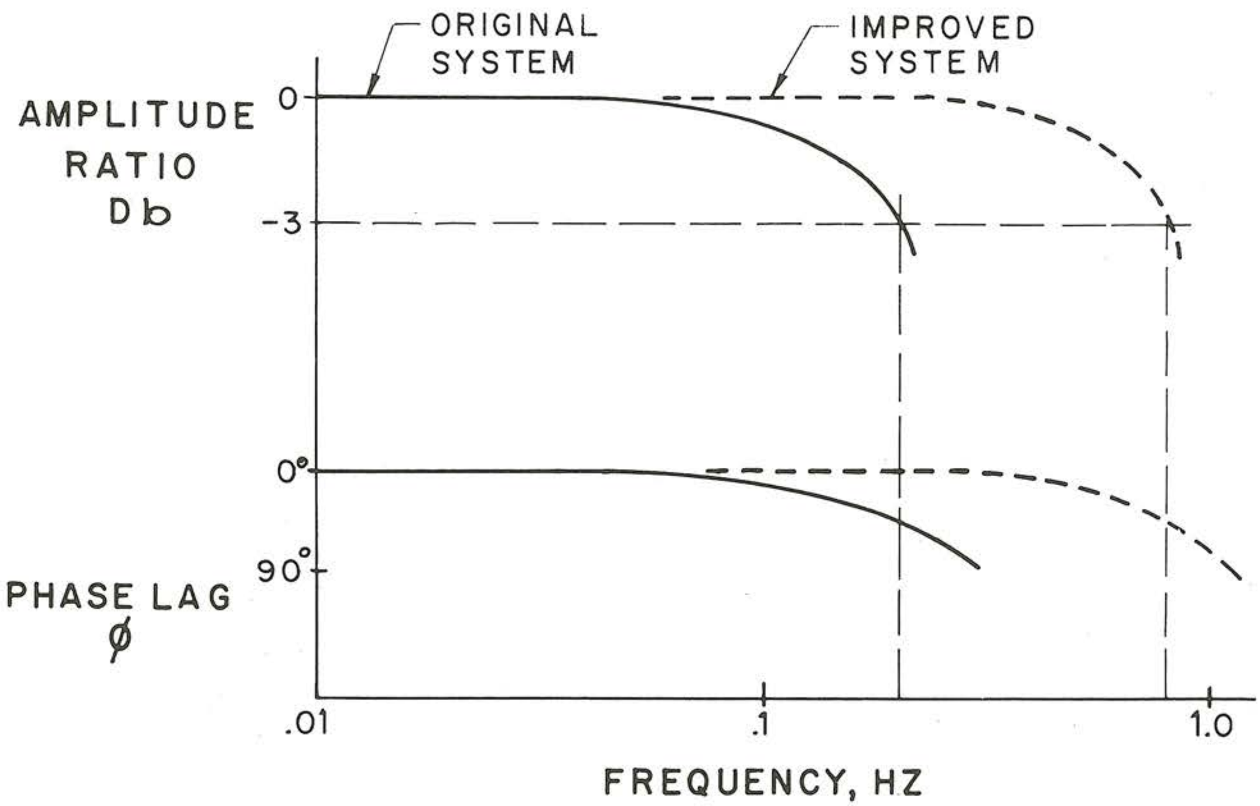
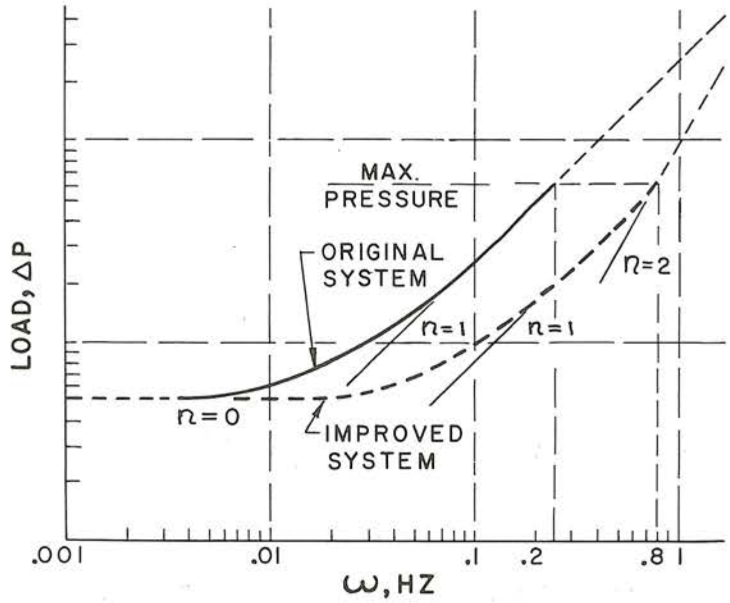


Figure 18. Roll Frequency Response



$$\Delta P = M a + B v + K x$$
$$= M\ddot{x} + B\dot{x} + Kx$$
$$= (-M\omega^2 + B\omega \angle 90° + K) x_{MAX} \sin \omega t$$

Figure 19. Visual Display Mechanism Load

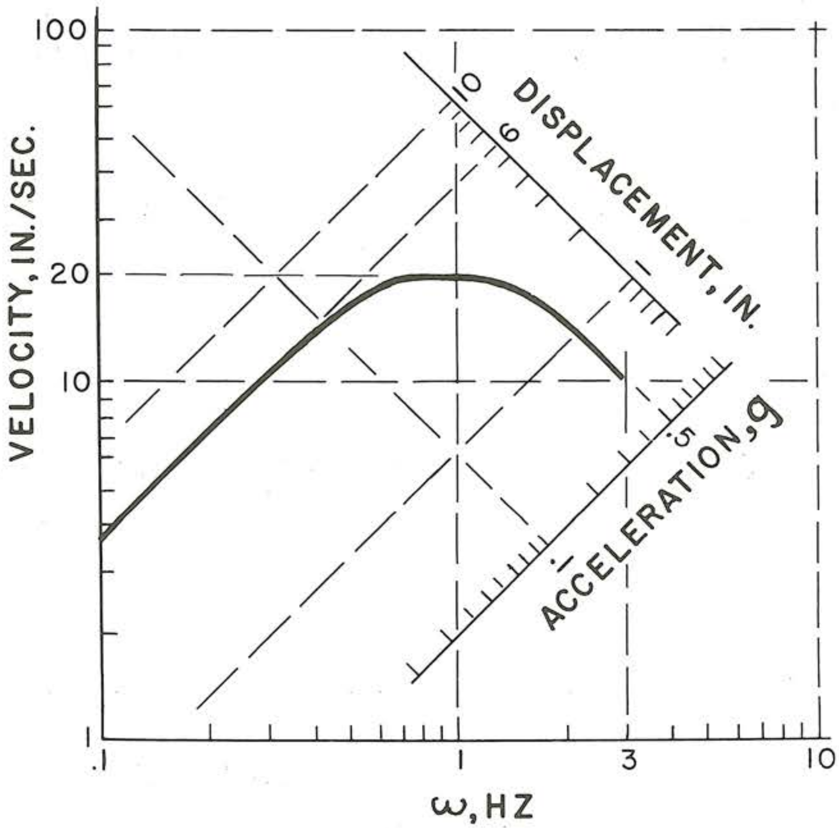


Figure 20. Motion Platform Performance

Visual Simulation Laboratory. This curve defines the limiting envelope of displacement, velocity and acceleration requirements at all points within its frequency bandwidth. This would be preferred to than just specifying maximum amplitude of displacements, velocities and accelerations without frequency considerations as has been apparently done in the past.

EXPERIMENTAL TEST PROGRAM

The present and future test and evaluation programs (except for platform motion) are based on recommendations from the various studies on NTDC Device 2FH4. The completion of the testing for the present task is scheduled for reporting in Dec of 1971. Validity tests of the T-28 Flight Simulator, will establish its perceptual fidelity to the aircraft it simulates less the display. Qualitative indications of the instruments response to cockpit control inputs have been completed. Quantitative tests of the instrument response for lateral and longitudinal stability have been started. The second item is Validity of Flight Simulator-Visual Display Characteristics. This includes dynamic testing of the visual mechanism for frequency response to meet the T-28 performance requirements which have been completed. The combination test will involve a pilot flying the aircraft to a contact flight landing. The criterion here will be pilot performance in making visual landings on a runway in accordance with rating techniques to be set forth in a report being prepared by Mr. Moe Aronson, Head of the NAVTRADEVCEN Visual Simulation Laboratory. The tests to determine design parameters for visual displays for specific missions would include experimental designs devised by the Human Factors Laboratory. The next item Validity of Motion Platform Characteristics include dynamic tests which have been completed. Further threshold acceleration measurements and threshold experiments are intended. And finally Specific Motion and Visual interactions will cover effects of visual distortion due to eye displacement to platform motion. This would also include effectiveness of math model of simulated motion cues.

The proposed tests beyond the present task would continue with tests to determine design parameters and would involve effects of reducing the level of brightness, and effects of varying contrast ratios of selected targets. The tests to determine application of training of specific visual tasks would cover (1) resolution or recognition of checkpoints for low altitude navigation (2) effects of transparency scale on low altitude observation, and air to surface attack missions (3) adequacy of forward visible missions (4) effect of limitation on visual display displacements in pitch and roll, (5) scoring of surface attack mission (6) training techniques studies based on initial flight conditions and (7) visual display for creating illusions of aircraft spins. The Specific Motion and Visual Interactions would also be continued from the present task to include determinations of amount of motion necessary to prevent conflict between visual and motion cues and to determine the extent of improvement of pilot performance with addition of motion.

SUMMARY AND CONCLUSION

In summation we can state that the recent efforts for combining the visual and motion systems indicate the trend for considering the man and machine as a system unit.[5] This is shown by the block diagram of the pilot and the simulator in figure 21. It is seen that the pilot has three

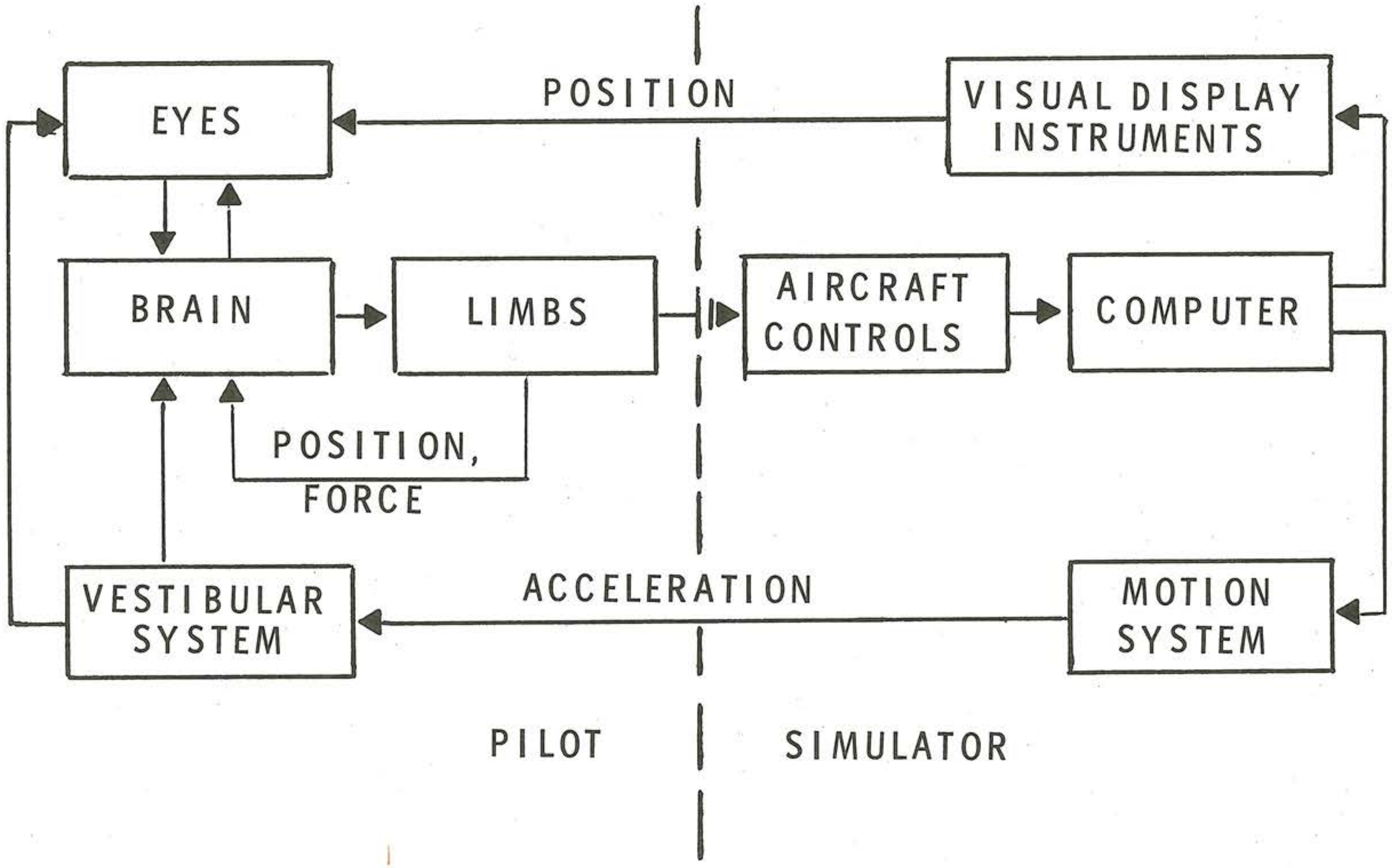


Figure 21. Block Diagram of Pilot and Simulator

main input sources for information: First, his eyes, which provide the main input. The information from his instruments and the visual scene tells him his attitude, position in space, and to a lesser extent, the rate of change of these variables. Second, his limbs, which tell him the position of the vehicle controls, the force he is exerting on them and the external forces on them. Third, the vestibular system which tells him when he is subjected to acceleration. And it also stabilizes the eyes during motion.

If a sudden disturbance is applied to the simulator he is immediately alerted through the vestibular system and is thus prepared to detect any visual or instrument changes. The visual indication will be delayed due to the inherent lag of the visual response, but the motion cue permits a faster pilot response for applying a correction to the pilot control. This brings another feedback loop into operation which tells the pilot how much he has moved the controls. An interaction occurs here since the aircraft acceleration generated by the controls displacement is sensed by the vestibular system and the pilot knows the correction is taking effect even though the instrument is indicating the result from the previous disturbance. In the case of the kinesthetic cues the pilot has even a quicker response to acceleration and has the added possible advantage, where the pilot can distinguish, between an aircraft response to outside disturbances and the aircraft response to his control movements. The pilot is thus able to predict what is going to happen to the simulator by means of these feedback loops, and build up pattern habits similar to those used in the aircraft. Whereas, in a simulator without motion, the pilot is deprived of the fast acceleration feedback and so he builds up an entirely different habit pattern.

In conclusion we may state that the point light source system is presently the only 360° non-programmed visual system in existence. Recent NAVTRADEVCEN reports have investigated multichannel TV systems as a potential technique for wide angle presentation but as yet no hardware has been built. The resolution and brightness is recognized to be the major drawbacks to the training utilization of the visual point light system, though not detrimental to the research tasks outlined. Plans have been underway for a new point light source optical system at the NAVTRADEVCEN Visual Simulation Laboratory which would provide improved uniformity of screen luminance and increased brightness by a factor of about four, and improved display resolution. In addition, laser technology has progressed so that laser light will be a possible light source in the near future. This could permit an extremely small spot with considerably more brightness than with conventional light sources. Finally, there appears to be a definite advantage for the addition of motion to visual systems, where the mission requires pilots to acquire habit patterns, similar to those obtained through actual aircraft training. However, considerably more basic knowledge is still required on the interactions of combined motion and visual cues for accurate representation of an operational situation.

References

1. Matheny, W.G., Lowes, A.L., Baker, G., Bynum, J.A., An Investigation of Visual, Aural, Kinesthetic and Motion Cues, NAVTRADEVCEN 69-C-0304-1, April 1971.
2. Puig, J.A., Motion in Flight Training: A Human Factors View, NAVTRADEVCEN IH-177, October 1970.
3. Klaiber, R.J., Investigation of the Imaging and Luminance Characteristics Associated with Point Light Projection, NAVTRADEVCEN IH-44, October 1965.
4. Sinacori, J.B., Application of the Northrup Rotational Simulator to Helicopters and V/STOL Aircraft (User's Guide), Northrup Corporation, Hawthorne, California.
5. Borlace, F.H., Flight Simulator Motion, Its Enhancement and Potential for Flight Crew Training. Third International Simulation and Training Conference. New York, New York, April 24-27, 1967, p. 60-65.
6. Aronson, M., Wide Angle Visual Simulation Requirements and Experience. AIAA Simulation For Aerospace Flight Conference, Columbus, Ohio, August 26-28, 1963.

PROGRAM

Tuesday, 15 February 1972
SESSION I

Dr. James J. Regan, Chairman
Head, Human Factors Laboratory
Naval Training Device Center

0900 Open Conference

0905 Introduction
Captain F. H. Featherston, U.S.N.
Commanding Officer, Naval Training Device Center

0915 Presentation on Naval Training
Vice Admiral M. W. Cagle, U.S.N.
Chief of Naval Training

0945 Conference Theme
Dr. H. H. Wolff, Technical Director and Conference General Chairman
Naval Training Device Center

1000 Transfer of Instrument Training and the Synthetic Flight Training System
Dr. Paul W. Caro
Human Resources Research Organization, Division 6 (Aviation)

1025 Coffee Break

1045 Effects of Training Situation Analysis on Trainer Design
Mr. N. R. Holen
McDonnell Aircraft Company, St. Louis, Missouri

1110 Quantitative Task Analysis and the Prediction of Training Device Effectiveness
Dr. A. Mirabella and Mr. G. R. Wheaton
American Institutes for Research

1130 Lunch

Tuesday, 15 February 1972
SESSION II

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

1300 Open Session II

1305 A Modified Model for Visual Detection
Dr. R. C. Sugarman, Mr. H. B. Hammill, Mr. J. N. Deutschman
Cornell Aeronautical Laboratory, Inc.

1325 Semiconductor Laser Applications to Military Training Devices
Mr. Albert H. Marshall
Physical Sciences Laboratory, Naval Training Device Center

1350 Digital Radar Land-Mass Display Simulation
Mr. R. A. Heartz
General Electric Company, Daytona Beach, Florida

1415 Design and Production of Antireflection Coatings
Mr. Denis R. Breglia
Physical Sciences Laboratory, Naval Training Device Center

1440 Coffee Break

1500 140° Close Approach Optical Probe for Visual Simulation
Mr. Albert Nagler
Farrand Optical Company, Inc.

1525 A New Assessment of Wide-Angle Visual Simulation Techniques
Mr. Moses Aronson
Head, Visual Simulation Laboratory, Naval Training Device Center

1550 Special Performance Lenses for Eidophor Real-Time Dynamic Full-Color Large-Screen Displays
Mr. H. C. Hendrickson
Philco-Ford, Western Development Laboratories

1615 Session II ends

1915 Social Hour, Hemisphere Lounge

2015 Banquet, Ballroom of the Americas
Toastmaster: Mr. E. X. Blaschka
Head, Program Control Department, Naval Training Device Center

Address by the
Honorable Robert A. Frosch
Assistant Secretary of the Navy for
Research and Development

Wednesday, 16 February 1972
Session III

Mr. Edward H. Grace, Jr., Chairman
Head, Field Engineering and Support Department
Naval Training Device Center

0830 Configuration Management-An Asset to Training Devices Production and Navy Support
Mr. John J. Regan
Modification and Maintenance Engineering Division
Naval Training Device Center

0855 The Universal Display Panel
Mr. Donald E. Reed
Electrical and Mechanical Trainers Division
Naval Training Device Center

0920 Real-Time Projected Displays
Mr. R. E. Thoman
General Dynamics Corporation, Electro Dynamic Division

0945 Built-In Test (BIT) for Training Devices
Mr. L. A. Whalen and Mr. M. P. Gerrity
Maintenance Engineering Division, Naval Training Device Center

1010 Coffee Break

1030 The DRAGON Antitank Missile System Training Equipment and Gunner Training
Mr. C. J. Whitman
McDonnell Douglas Astronautics Company

1055 Introduction
Colonel M. H. Mierswa, Sr., U.S.A.
Commanding Officer, U.S. Army Training Device Agency

1100 Innovations in the Army's Training Program
General Ralph E. Haines, Jr., U.S.A.,
Commanding Officer, U.S. Continental Army Command

1130 Innovations in Land Combat Training
Mr. B. L. Sechen, Deputy Director of Army Projects
U.S. Army Training Device Agency

1200 Lunch

Wednesday, 16 February 1972
Session IV

Mr. Emerson J. Dobbs, Chairman
Head, Sea Requirements and Plans Department
Naval Training Device Center

1315 Open Session IV

1320 Introduction
Colonel J. M. Terry, Jr., U.S.M.C.
Marine Corps Liaison Officer
Naval Training Device Center

1325 Marines-Past, Present, and Future
Lieutenant General Ormond R. Simpson, U.S.M.C.
Deputy Chief of Staff (Manpower)/Director of Personnel
Headquarters, Marine Corps

1345 Surface and Subsurface Program Requirements
Mr. E. J. Dobbs
Naval Training Device Center

1410 Undersea Warfare Training Device Requirements for the Next Quarter Century
Mr. Alan J. Pesch, Chief, Man/Machine Systems
Electric Boat Division, General Dynamics Corporation

1435 The Farrand Ground Effects Projector
Mr. J. A. La Russa
Farrand Optical Company

1550 Coffee Break

1520 Advances in Sonar Audio Simulation
Mr. Edward J. Wrobel
ASW Tactics Trainers Division, Naval Training Device Center

1545 Multiple Oscilloscope Trace Generation for Analog Computers
Dr. Klaus W. Lindenberg and Mr. Paul E. Speh
Florida Technological University

1610 Electromagnetic Compatibility of Training Devices
Mr. R. N. Hokkanen
Maintenance Engineering Division, Naval Training Device Center

1630 Session IV ends

Thursday, 17 February 1972
Session V

Mr. Victor G. Hajek, Chairman
Head, Air-Warfare Department (ASW/Environmental)
Naval Training Device Center

0830 Needed: A Strategy for the Application of Simulation in The Curricula Proposed Training Systems
Dr. Thomas R. Braby
Land/Sea Trainers Applications Div., Naval Training Device Center

0855 Tradeoff Criteria for Specification of Prime or Simulated Computers in Training Devices
Mr. A. E. Mergy
Hughes Aircraft Company

0920 Instructor Console Instrument Simulation
Mr. I. V. Golovsenko and Mr. J. L. Booker
Naval Training Device Center, Computer Laboratory

0945 Status of Computer-Generated Imagery for Visual Simulation
Mr. M. G. Gilliland
General Electric Company, Apollo Division

1010 Coffee Break

1030 Computer-Assisted Instruction (The SFTS as a Computer Controlled Training Device)
Mr. D. E. Trundle
Singer Company, Link Division

1055 Safety Aspects in Aviation Physiological Training Devices
Mr. Hans W. Windmueller
Land/Sea Trainers Modification Division
Naval Training Device Center

1130 Lunch

Thursday, 17 February 1972
Session VI

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

1300 Trends in Naval Aviation Training
Captain D. W. Nordberg, U.S.N.
Head, Air Training Section, Chief of Naval Operations, U.S. Navy

1325 Air Program Requirements
Mr. Arnold E. Allemand, Jr., Head, Air Requirements and Plans Department, Naval Training Device Center

1350 Application of Advanced Simulation Technology to Pilot Training
Mr. J. F. Smith and Mr. D. W. Simpson
Singer Company, Link Division

1415 Automated GCA-Final Approach Training
Dr. J. P. Charles and Mr. R. M. Johnson
Logicon, Incorporated

1440-1445 Closing Remarks, Captain F. H. Featherston, U.S.N., Closing Conference, Dr. H. H. Wolff

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Training Device Center Orlando, Florida 32813	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Proceedings of the Fifth Naval Training Device Center/Industry Conference

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

Key personnel--Naval Training Device Center and Industry

6. REPORT DATE 15-17 February 1972	7a. TOTAL NO. OF PAGES 326	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NAVTRADEVCEN IH-206 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Training Device Center Orlando, Florida 32813

13. 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.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
CONFERENCES--NTDC/INDUSTRY						
INDUSTRY						
MILITARY						
SIMULATION TECHNOLOGY						
TRAINING DEVICE TECHNOLOGY						
TRAINING METHODOLOGY						
TRAINING SIMULATION INDUSTRY						
CONFERENCES--Twenty-five YEARS OF TRAINING SIMULATION--SPRINGBOARD FOR THE FUTURE						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification